PROCEEDINGS

OF THE

BELFAST

Natural History and Philosophical Society.

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PRESIDENTIAL ADDRESS

ON SOME QUESTIONS IN

COSMOLOGICAL SCIENCE,

DELIVERED BY

JOSEPH JOHN MURPHY, Esq.,

ON NOVEMBER 13, 1872.

In the present address I design to make some remarks on a few of the most interesting of the problems which are either in the way of being solved, or waiting for solution, in what may be called the cosmological sciences. I hope you will not think it insufferably pedantic to use such an expression as cosmological science. No one has a right to use an unfamiliar term where a familiar one will serve equally well, but I have a meaning here which no single familiar word will express. The physical sciences fall naturally into two groups. The first regards the laws, properties, and forces of matter as they are in themselves. To this group belong chemistry, and what was formerly called natural philosophy, and all the experimental sciences. The second group regards the same laws, properties, and forces, not as they are in themselves when isolated in the laboratory of the experimentalist, but as they are seen in the results which they produce when at work in the universe; and it is these which I call the

cosmological sciences. To this group belong astronomy, geology with physical geography, meteorology with the theory of climate, and that science which has been rather absurdly called the physical geography of the sea, but for which we ought to introduce the word oceanography. These collectively form cosmology, or the science of the universe. This word is needed partly in order to indicate the fact that these sciences form a well marked natural group; and partly because their boundaries as between each other are growing less and less distinct. It may appear strange, that with the advance of knowledge it should become not easier, but more difficult, to trace the boundaries of the various sciences; but this is often true, and it is true here. A century ago, astronomy, geology, and meteorology all appeared perfectly distinct. Astronomy was the science of the heavens, geology of the earth, and meteorology of the air. But now we have learned something of the geology of the moon, and we are learning much of the meteorology of the sun. The subject of the changes of climate which have occurred during geological periods, to which I shall have to ask your attention further on, belongs equally, though in different ways, to meteorology, geology, and astronomy. And if the nebular theory of creation—that is to say, the theory that all the worlds of which the suns and planets are composed came into existence by the slow condensation of a mass of nebulous matter—if this theory, I say, is to be regarded as approximately proved, it constitutes the root out of which those three sciences diverge, and back to which the origin of their facts is to be traced.

It is, no doubt, a startling speculation this, that all the matter of which the heavens and earth are formed existed at first in a diffused nebulous state, and that all the facts of cosmological science—all the phenomena of heaven, of earth, of air, and of ocean—are but incidents in the process of its condensation. There are, however, extremely strong reasons in favour of this theory, though I do not say it is free from difficulties; but it would require a separate address to state those reasons in even the barest outline. If it is true that all the stars and planets have been formed out of what was originally a single nebulous mass, we may reasonably expect to find that chemical elements are the same throughout the entire stellar system; and this to a great extent is the fact. It is now certain that meteoric stones are small planet-like bodies, which have come from the space external to the earth's atmos-

phere, and the substances of which they are composed are all chemically identical with substances that we know on this earth. Iron is one of these. And, moreover, the new and wonderful art of spectrum analysis, which has made it possible to ascertain the chemical constitution of a source of light by the examination of a ray of the light which it emits, has shown that many of the same chemical substances, both metals and gases, which exist in this planet, exist also in the sun, in many of the stars, and in the nebulæ.

This, however, must not be overstated, as if all parts of the universe were exactly alike in chemical constitution. One of the most wonderful facts revealed by spectrum analysis is that the luminous globe of the sun is surrounded by an atmosphere of hydrogen; and the same is true of some of the stars. This is very unlike the earth's atmosphere, in which there is no free hydrogen at all. The existence of atmospheres of free hydrogen in various parts of the universe, which is thus proved, must be in some way connected with what is one of the strangest facts in cosmological science—namely, that some meteoric stones contain hydrogen, and appear to have passed through an atmosphere of heated hydrogen. The atmospheres of the different planets also appear to differ in chemical constitution. Spectrum analysis gives information, not only about the source of the light submitted to it, but also about the medium through which the light has passed, and consequently is able to show something of the constitution of the atmospheres which surround the planets, and through which they reflect the sun's light; and this test appears to show the presence of substances in the atmospheres of the planets Jupiter and Saturn, which are unknown to us. The light of different stars also gives proof of differences of chemical constitution—some resemble the sun, while others are very different; and it is worthy of remark, though in no degree surprising, that in some cases a particular chemical constitution is characteristic of the stars of particular regions of the heavens. It is a fact of the same kind, that among the meteors which enter the earth's atmosphere from planetary space, those of August and those of November are shown by spectrum analysis to be in some degree unlike in chemical constitution. There appear to be also differences of chemical constitution between different planets; thus, the well-known red colour of Mars must be due to some sub-

stance which, if it exists in the earth at all, is at least much more abundant in Mars than here. The likeness between the earth and Mars is, however, more remarkable than the unlikeness. The surface of Mars, like that of the earth, is divided between sea and land, and the regions round both its poles are seen to be covered with snow. The differences of chemical constitution between the different suns, planets, and meteors appear to be a difficulty in the way of the nebular theory ; for if it is true that all had their origin in one vast nebula, we might expect that nebula to be of uniform constitution throughout, and, consequently, that all the bodies formed out of it should be chemically alike. But this difficulty ought not to be regarded as a conclusive objection to the theory. Perhaps, if we understood the physicial conditions of the nebula when it first began to condense into suns and planets as well as we understand the physicial conditions of the earth with its ocean and its atmosphere, the differences of chemical constitution between different suns and planets would be as easy to account for as the differences of chemical constitution between the various rocks that compose the earth's surface. Now it is scarcely possible to doubt that the processes which went on in the nebula during its condensation were immensely complex, and that they were not only physical and mechanical, but also partly chemical. I have already mentioned one of the most surprising of all cosmological facts—a fact which but for spectrum analysis would never have been suspected—namely, the existence of an atmosphere of free hydrogen around the sun and above its luminous clouds. In the earth's atmosphere, oxygen predominates over hydrogen: there is no free hydrogen, but there is free oxygen. In the sun's atmosphere the reverse appears to be the case: there is free hydrogen, and the fact that spectrum analysis does not reveal the existence of free oxygen appears almost to amount to a proof that it does not exist, for if it existed it could not fail to be carried up into the region of hydrogen by the enormously violent boiling motion which the sun's heat produces in his atmosphere. It appears the opposite of what might have been expected, thus to find a comparative abundance of hydrogen, which is the lightest of all known substances, at the centre of the solar system, where we might expect to find the heaviest substances accumulated in virtue of their

weight. I cannot make any assertion as to the true reason of this fact, and perhaps it may never be explained, but I will offer what appears to be at least a possible explanation. It may be that the preponderance of hydrogen over oxygen in the sun is only apparent. It may be that the proportion of oxygen to hydrogen is really as great or greater in the sun than on the earth, but that the oxygen has been all combined with metals, some of them perhaps heavier than any known to us, which have accumulated in the sun, at the centre of the solar system, by reason of their weight.

So far as is known to us, there appears to be at present very little chemical action of any kind going on in any part of the universe. It is certain that the heat of the sun and of the rest of the stars cannot be due to chemical action. The nebular theory, or, as it may be called, the condensation theory, of the origin of the stellar system, offers an explanation of their heat as being due to the process of condensation. When any moving body is brought to rest, the energy due to its motion is not destroyed—energy cannot be destroyed any more than matter—it is transformed into some other kind of energy, generally into heat. This is the explanation of the heat produced by friction, which is one of the most familiar of all facts, and collision produces heat in the same way. The nebular or condensation theory explains the heat of the sun as being due to this source. In consequence of the enormous force of gravitation due to the sun's enormous mass, this is a far more abundant source of heat than any combustion could be. A globe of coal as large as the sun, and emitting heat at the same rate, would be burned away in about five thousand years. On the contrary, the collision of the particles which must have taken place in the condensation of the sun's mass from the state of nebulous vapour, was more than sufficient to produce heat enough to supply the earth and the other planets with a greater quantity of heat than they are receiving now, through the entire duration of geological time. And the same cause is most probably still at work. It is true that the sun is no longer in the nebulous state, but it is probable that the process of condensation has not ceased. The sun may at present be gradually though very slowly cooling, but even on the supposition that he is remaining at the same temperature, and that he is receiving no streams of fresh matter from external space, it is possible that the present supply of

solar heat may be continued for a time in comparison with which all historical time is as but a moment, merely by the progressive condensation of the sun's mass. All bodies at a high temperature shrink and diminish in volume as they give out heat. In the case of a mass of red hot iron, this shrinking or contraction is a source of fresh heat to but an imperceptible extent; but in the case of the sun it is quite different—gravitation at his surface is so powerful, that as his volume contracts the upper strata of his globe will fall in towards the centre with a force sufficient to generate all the heat that he emits. I speak of the falling in of the upper strata, in order to give a definite image. The expression suggests the falling in of rocks; but it does not matter whether the substance of the sun is solid or liquid, or whether the contraction of his volume takes place by uniform subsidence or by a sudden crash repeated at short intervals; the same quantity of heat is due to the descent of a given mass through a given height under the influence of a given force, no matter under what circumstances the descent may take place. The sufficiency of the source here assigned for the sun's heat is a subject for calculation. The sun's magnitude is known with almost perfect accuracy, and his weight, and the quantity of heat which he emits, are approximately known; and from these data it has been calculated by Helmholtz, that the heat now given out by the sun in a year is equal to that which would be engendered by the contraction of his volume by one twenty millionth part of his diameter. This is equivalent to the subsidence, or sinking in, of his surface at the rate of about 120 feet a-year; a change which, I need scarcely say, could be discerned by no possible delicacy of astronomical measurement. It appears most probable that this is the chief source of solar heat, but it is not the only source. Meteors are constantly falling into the earth's atmosphere, where they appear as what are most inaccurately called falling stars. From all that we know of the orbits in which they move round the sun, and from the distribution of planets and comets through space, we have every reason to believe that meteors must be very much more numerous in the immediate neighbourhood of the sun than in our part of planetary space, and that they fall much more abundantly into the sun's atmosphere than into ours: and as the fall of meteors is accompanied with light and heat, we cannot doubt that this is a

source of at least part of the sun's heat. But is it a perceptible part? There are what I regard as strong reasons for believing that it is. Meteors are small planets, and it is probable that, like the larger planets, their motion is generally from west to east round the sun. The eminent astronomer Mr. Carrington once saw two meteors, which were, no doubt, the fragments of one, so bright as to appear bright on the sun's disc, moving across his disc from west to east. Further, it is probable that, like other planets, the meteors move round the sun in orbits which are approximately parallel to the sun's equator, or at least inclined to it at an average angle of less than 45 degrees; and if this is the case, they must fall into the sun's atmosphere in greater numbers near his equator than near his poles, for the same geometrical reason that more of the sun's light and heat falls on the earth's equatorial than on its polar regions. I do not say that this distribution of meteors on the sun's surface is by any means proved, but it offers an explanation of some facts which, so far as I see, cannot be otherwise explained. It has been ascertained by means of a very delicate electric thermometer, that the equatorial regions of the sun are hotter than his poles. This, it is obvious, cannot be due to any cause like that which makes the earth's equator hotter than its poles; but it may be due to the greater number of meteors that fall in near the sun's equator. This, however, is not all. The sun, like the earth, rotates on his axis, and, as we have seen, is hottest at the equator. We might, consequently, expect to find that in the sun's atmosphere, as in that of the earth, there should be trade-winds—that is to say currents of air from east to west—on each side of the equator. But we do not find such currents in the sun's atmosphere. On the contrary, we find the exact opposite. Mr. Carrington, the same careful and acute observer who saw the meteors on the the sun's disc, has ascertained, by observing the motions of the spots in the sun, that the currents of the sun's atmosphere are in the opposite direction to that which the theory of the trade-winds would lead us to expect. In other words, the atmospheric currents in the equatorial regions of the sun are not from east to west, but in the direction in which the planets revolve, from west to east. This would be the effect of a constant shower of meteors entering the sun's atmosphere, with a motion from west to east. Further,

there is more appearance of violent agitation near the sun's equator than near his poles, and the solar spots which, whatever they are, are due to atmospheric disturbances of some kind, are never seen in his polar regions. These facts again are a probable result of a more abundant fall of meteors near the equator than near the poles. Do not, however, mistake me as if I were advocating what is called the "meteoric theory of solar heat." I have given what I think very strong reasons for believing in the existence of the solar meteors, but there are astronomical reasons for believing that this source is quite insufficient to account for all the heat with which the sun must have warmed the earth through the ages of geological time. The chief source of the sun's heat is most probably the condensation, or contraction, of his own mass.

I have alluded to those most mysterious phenomena, the solar spots. It appears certain that these are produced by revolving storms in the sun's atmosphere, and we find, as theory would lead us to expect, that revolving storms in the atmosphere of the sun, as in that of the earth, are never to be seen precisely upon the equator. But why do revolving storms appear as dark spots? This is a question to which, so far as I am aware, no satisfactory answer has been given.* We have, however, learned very much about the constitution of the sun's atmosphere. Spectrum analysis has added so much to our knowledge that all works on the subject of an earlier date than its introduction are now quite superseded. It appears certain that what we see of the sun consists of clouds, formed very much as the clouds of our own atmosphere are formed, but precipitated, not from watery vapour, but from the vapour of iron and other substances which are solid at terrestrial temperatures. Much has been said about the form of these clouds. One observer compares their shape to that of willow leaves, another to grains of rice, another to bits of straw. This, however, is a subject of no great scientific importance, and it ought to be remembered that we never see their forms truly. Their forms, as seen by us, are distorted by the powerful refraction and violent agitation of the atmosphere in which they float. Every one must have noticed the apparent tremulous motion of objects seen in the open air over a

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* See Mr. Murphy's paper "On the Solar Spots" in the present volume.

fire, and everything in the sun's atmosphere is seen by us through such a medium, but in a state of incomparably greater agitation. It is probable that the forms of the spots, as seen by us, are even more distorted than those of the ordinary clouds, because the spots are formed lower down in the atmosphere, and are, consequently, seen through a greater thickness of refracting medium; and also because they are formed in the midst of the greatest agitations.

The two greatest mysteries in the cosmological sciences which are at the present time waiting solution are the nature of the sun's spots, and of the comet's tail. Concerning comets, one most important discovery has been made, connecting them with meteors, though it does not appear to throw much light on their physical constitution. Those small planetary bodies which appear as meteors when they enter the earth's atmosphere are not evenly scattered through planetary space, but are found chiefly in certain narrow tracts of space, which constitute their orbits round the sun. There are, probably, very many of these meteor orbits, but the positions of only two have been ascertained. These two are intersected by the earth's orbit, one in August and the other in November, and give origin respectively to the August and the November meteors. Now, it has been ascertained that each of these meteor orbits coincides with the orbit of a comet. There can be no doubt that this is more than a mere coincidence, and that there is a physical connexion in each case between the comet and the meteors, though the nature of the connexion is quite unknown. But, whatever the connexion may be, it is not identity. I am aware that the opinion has been lately advanced on high authority, that a comet's tail consists of a multitude of the meteors, but this could never have been propounded by any one who had the facts in his mind's eye which are known about the tail. Those facts all tend to show that the visible parts of a comet, head and tail alike, consist of clouds which are suspended in an atmosphere too thin and transparent to be visible to us. This is almost proved by the fact that in many cases there is an invisible space between the head and the tail: this cannot be absolutely vacant, but may be compared to clear spaces of air between clouds in our atmosphere. We may say, indeed, that the formation of the clouds which constitute the visible part of the comet has taken place under our eyes; for

Halley's comet, in 1836, appeared to grow larger as it receded from the sun—a fact which can only be accounted for by supposing that what had been kept in the state of invisible vapour by the intense heat when the comet was at its nearest to the sun, was condensed into visible cloud when the comet came into a cooler region. The supposition that the clouds which constitute the visible part of the comet are surrounded with an invisible atmosphere of great and unknown extent, in which the clouds are formed and into which they may be dissolved, will alone, as it appears to me, account for the phenomena of the tail, especially for the remarkable fact that the tail always points away from the sun, even while the comet is in the part of its orbit where it moves with the greatest rapidity. The great comet of 1843 (the head of which was not visible in our latitudes), when it came nearest to the sun, swept its tail round through a semicircle in little more than two hours, and yet its tail was nearly equal in length to the distance that separates the sun from the earth. Were the tail a rigid rod sticking out from the comet's head, such a sweep as this would be altogether inconsistent with the laws of motion; and it is, if the expression can be admitted, still more impossible in the case of a substance of such tenuity as the tail of a comet. But it becomes in a great degree intelligible if we suppose that the tail does not consist of the same particles in successive moments, but is constantly being formed by condensation at that side of the comet's atmosphere which is turned away from the sun, and as constantly being evaporated. The same comet of which I have been speaking at one time formed a second tail, nearly twice as long as the ordinary one, and consequently of a length probably greater than the distance between the earth and the sun, which, however, was only seen on one night, neither before nor after. To suppose that this second tail was thrown out from the head and absorbed back again, is to suppose the action of forces not only incomparably more energetic than any with which we are acquainted, but totally unlike them in kind. But the phenomenon becomes quite intelligible if we suppose that the second tail was a cloud which was condensed from an invisible atmosphere and dissolved into it again by evaporation. Finally, there is the very curious fact that Biela's comet was seen, at its last appearance, to divide into two comets, which, however, continued to keep near

each other. If what appeared to be two comets were really only two clouds contained in one invisible atmosphere, there is nothing very marvellous about this fact; otherwise it appears totally unintelligible. It is, indeed, scarcely any exaggeration to say that the formation of the comet's tail by a process of evaporation and condensation has been seen by the telescope. The last time that Halley's comet was visible, in 1836, jets were seen to issue from the head towards the sun, and these were bent in a way which Sir John Herschel compares to steam or smoke blown aside by a powerful wind, so that they flowed round to the further side of the comet, and were lost in the tail. The form and number of these jets varied from day to day, and their direction was seen to vary even from hour to hour.

What is most remarkable about the structure of a comet is the peculiar form of the tail. This appears to be hollow; it is only thus we can account for the space of faint light between the bright streamers on each side. No attempt, so far as I am aware, has been made to account for this. But I ought to mention a most ingenious and probable suggestion, which our distinguished fellow-countryman Professor Tyndall has made respecting the mode of the formation of the visible clouds of the head and the tail, from the invisible atmosphere in which they are suspended. He has ascertained that some vapours are decomposed by the passage of light through them, and yield under its influence a liquid or solid precipitate, which forms clouds. The vapour which has this property in the highest degree is that of nitrite of amyl. When it is enclosed in a glass tube, and a ray of bright sunlight or of the electric light sent along the tube, the light decomposes the vapour, and forms, as Professor Tyndall believes, nitrate of amyl, which is unable to remain in the state of vapour at the temperature of the vapour of the nitrite, and consequently assumes the liquid state; but, like liquid water when condensed from its vapour in the air, it does not at once fall in rain, but remains suspended in the vapour in the form of a white but transparent cloud. In its extraordinary tenuity, this cloud resembles the tail of a comet. Professor Tyndall says "Placing a page of print so that it might be illuminated by the cloud itself, it could be read through the cloud without any sensible enfeeblement. Experiments proved that matter of almost infinite tenuity is competent to shed forth light far

more intense than that of the tails of comets. The weight of the matter which sent this body of light to the eye would probably have to be multiplied by millions to bring it up to the weight of the air in which it hung." Elsewhere, he says that in his opinion a few ounces of the vapour of iodide of allyl, another substance which has the same property, would be sufficient to form the visible part of one of the largest comets. A comet resembles the clouds here described, and at the same time differs from atmospheric clouds, in being so transparent as not to dim the light of the smallest stars. But why, on this theory, does the tail stretch away from the sun? In order to understand any possible reason for this, we must remember that the cloud in Professor Tyndall's experiment is not precipitated by the heat which accompanies the light, but by the chemical, actinic, or photographic rays. We must suppose that it is the same in the comet, while the antagonist action of evaporating the clouds back into invisible vapours is due to the sun's heat. If, then, we suppose that the cloud which constitutes the head of the comet absorbs the heating rays of the sun while it permits the chemical rays to pass through, this will account for the cloud which constitutes the tail being formed in a direction stretching away from the sun. This is not advanced as a proved theory of comets, but as a probable hypothesis, and the only one which has the slightest appearance of truth. If spectrum analysis should detect in a comet's atmosphere the presence of any vapour which has this property of yielding a cloudy precipitate under the influence of light, this will almost amount to proof of the theory. If it is shown to be true, it will be remarkable as the only instance of chemical action known to take place in the universe on a very large scale.

In going on from astronomical to geological phenomena, we have still the same class of subjects and the same kind of forces to deal with. I now design to say a few words on the subject of volcanic action, and I think I can show that the natural history of the earth has a much closer resemblance to that of the sun than has hitherto been suspected. We have strong reason to believe that the earth at great depths is intensely heated. If the nebular theory is true, the central heat is the heat that was produced by the collision of the smaller masses which rushed together to form the earth, and it

is quite certain that no chemical process which can produce such heat, and indeed no chemical process at all of any importance, is now going on in the depths of the earth. The centre of the earth—and by the centre is meant all except a few miles of depth next the surface—the centre of the earth, I say, is thus a reservoir of heat, though not a fire where heat is produced, and it is an obvious and at first sight a plausible hypothesis, that volcanic action is due to the expansive force of this imprisoned heat. This opinion is, I believe, still widely prevalent among those who know the outline of the facts, without having reflected enough on them to perceive the difficulties of the question. But it is utterly unsatisfactory. The reservoir of heat is there, no doubt, in the depths of the earth, not many miles from the surface; but how is it to burst through the surface and break out in a volcano? The surface of the earth has already cooled, and when the internal heat has not had force enough to prevent the formation of this cold surface, how can it have force enough to break through the surface? As well might we suppose that the heat which remains in water after it has begun to freeze, could melt or break up the ice that has formed on it; or, to use a different illustration, we might as reasonably think it possible for the water in a reservoir to break out in a spring at a higher level than the surface of the reservoir. In order to set a volcano going, there must be a disturbance of the equilibrium either of heat or of pressure. It is generally agreed that volcanic action is a fact of the same class with changes of level and formation of mountain-chains, and that whatever theory accounts for the one ought also to account for the other; and the true theory of both is, I have little doubt, that which has been lately advanced by Mr. Mallet. These phenomena, according to him, are not due to the expansive force of internal heat, but to a cause which is the opposite, or rather the converse of this—namely, the contraction and subsidence of the surface on the interior. The heated interior of the earth is progressively though very slowly cooling, by reason of the slow conduction of its heat away through the superficial strata, and as it cools it must contract; while the surface cannot contract, because it is already cold. Thus, the earth is like an apple which shrinks in drying. The apple contracts, while its skin clings round it, and yet cannot contract. The effect in the case of the

apple is that the skin forms itself into wrinkles or ridges; and in the case of the earth the effect is the same; but the ridges on the earth's surface are hills, table-lands, and mountain chains. All the greater changes of level on the earth's surface are thus accounted for. This theory has the advantage, among others, that it explains much better than the rival theory of an expansive force acting from below, the phenomenon which is very common in mountainous countries, of strata which are bent and contorted, apparently by great lateral pressure. It is easy to see that such contortions must be produced in the process by which the earth's surface is wrinkled into mountain ridges. According to Mr. Mallet, volcanic action is not the cause but the effect of changes of level and the formation of mountain ridges: and the heat of volcanoes is not derived from the reservoir of heat in the centre of the earth, but is produced by the force with which the surface subsides, or settles down, on the interior, as the interior contracts. There can be no doubt that this is quite an adequate cause of volcanic heat. Suppose that the interior of the earth beneath an area of some thousands of square miles has shrunk in by even a few inches, and that the upper strata, of equal extent and of a thickness of a few miles, sink down after it; and suppose that the greater part ot the motive power due to the surface thus falling in is concentrated in bending or crushing rocks at a few points: heat will be produced in overcoming the resistance of the rocks, just as if the same force was expended in friction or collision, and the heat so produced will, no doubt, be sufficient to melt rocks into lava and to cause volcanic eruptions. We thus come to this very remarkable conclusion, which, if not proved, is at least highly probable, that the heat of the sun and the heat of volcanoes are produced in the same way—namely, by the motive power exerted in the subsidence or sinking of the external strata on the interior.

But, though all the greatest changes of level, including the formation of mountains, are due to the class of actions of which I have now spoken, or what may be called the internal action of the earth, yet they give by no means a complete account of the process by which the surface of the earth has assumed its present form and appearance. We may say with a rough approach to accuracy, that in giving the surface of the earth its present form and contour, two sets

of causes of equal importance have operated together, the internal and the external. By the internal causes I mean those which have now been spoken of—the forces that form mountain chains and break out in volcanoes. By the external causes, I mean those due to the air and the ocean. The geological function of the ocean in depositing strata has been known ever since geology became a science, and its effect in wearing away the land has long been recognised. The effect of rain and rivers in wearing away the land, and excavating valleys, is probably greater, though its full importance has been recognised only of late years. And in high latitudes, and among mountains, the effect of ice has perhaps been the greatest of all. The excavating power of glaciers must be obvious to any one who sees the quantity of mud that is carried away by the streams to which they give rise. It is certain that at a very recent geological period, the Alpine glaciers extended much farther down the valleys than they do now; and there are strong reasons for thinking that the valleys of the Alps have been excavated by the glaciers which once filled them.

We call the period of the great extension of glaciers the glacial period, and we call its climate the glacial climate. Few subjects are more controverted than the cause and nature of the glacial climate, and in my opinion few subjects are more misunderstood. It appears to be generally taken for granted, not only by ordinary readers but by scientific men, that the glacial climate must have been intensely cold; yet I have no hesitation in saying that this is altogether a misconception. A careful examination of the facts of physical geography will show, what might indeed have been expected, that the extent of snow-fields and glaciers depends on the summer climate; not on the temperature of the entire year, but only of the warmest part of the year. Thus the facts which prove the former existence of glaciers and icebergs where they are not seen now do not require us to suppose that the winter was intensely cold. But not only so—they actually forbid such a supposition. Icebergs once drifted in shallow seas over what are now Scotland, Denmark, and Prussia, and it is obvious that they could not have so drifted if the sea had been frozen. It appears probable that the climate of the glacial period resembles that which now prevails over part of the southern hemisphere in a latitude not higher than ours, where there

is winter all the year, and little difference of temperature between one month and another. If it is true, and I think it certain, though it does not appear to be generally admitted, that the greater or less extent of glaciers depends, not on the mean temperature of the year but only on the summer temperature, it follows that a glacial climate might be produced without altering the mean temperature of the year at all, by any cause which should make the summer cooler while it made the winter warmer. Such a cause is known to exist. Supposing the sun always to give out the same quantity of heat, the total amount of heat received at any particular latitude on the earth in the course of a year is almost invariable, but the distribution of the heat over the seasons of the year is liable to great changes. The eccentricity of the earth's orbit is subject to great fluctuations, at intervals which, geologically considered, are not very long. The eccentricity is now comparatively small—that is to say, the earth's orbit does not now differ much from a circle—but there have been periods when it was very different. At present the difference between the greatest and the least distance between the earth and the sun is only three millions of miles, but two hundred thousand years ago it was ten and a quarter millions, and eight hundred and fifty thousand years ago it was thirteen and a-half millions. One effect of this is, that if the quantity of heat received by the earth at the farthest point of its orbit from the sun is at present represented by the number 100, two hundred thousand years ago it was only 92, and eight hundred and fifty thousand years ago only 88. It needs no proof that this must have had a great effect on the climate of the various seasons of the year, but the nature of the effect must depend on another element of the problem—namely, the season of the year at which the greatest distance occurs. If the earth's greatest distance from the sun is unusually great, and occurs in summer, the effect of this will be a cool summer. All this is undisputed; and I further maintain, though this is not undisputed, that a cool summer is the cause of a glacial climate. As the seasons are reversed in the opposite hemispheres, so that when it is summer in the northern hemisphere it is winter in the southern, and *vice versa*, it follows that the two hemispheres can never be under a glacial climate at the same time. This, however, is no difficulty in the way of the theory. Clear and extensive proofs

of former glacial climates are found in both hemispheres, but though they belong to the same geological age, there neither is nor can be any proof that they were absolutely simultaneous. The duration of a period of great eccentricity of the earth's orbit is to be measured by some such period as 100,000 years, and during that period, if the theory I am endeavouring to expound is true, there must be glacial periods in the northern and southern hemispheres alternately at intervals of about 10,500 years. The reason of this is that the time of the sun's greatest distance does not always occur at the same period of the year, but is constantly changing at a uniform rate. If at any time the sun's greatest distance occurs at midsummer of either hemisphere, it will in 10,500 years have changed round to midwinter.

From the great amount of excavation in the ravines and river-beds of some parts of Europe, it has been argued that there must have been a pluvial, or rainy, period after the glacial, or during its subsidence. It is to be observed that a great rainfall does not by any means imply incessant rain. There are some tropical countries where the total rainfall is very great, and yet a great part of the year is dry. Now, if the theory of the glacial climate which I have endeavoured to explain, is true, it also follows that there must have been a great fall of either rain or snow at the time of the glacial climate. It is obvious that rain and snow may fall at the same time in regions not widely separated, and that either rain or melting snow will do exactly the same work in excavating river-beds. I have endeavoured to account for the glacial climate—in other words, for the great extension of glaciers—by the fact that there have been periods when the earth was far from the sun during the summer, so as to produce a low summer temperature. But when the earth was far from the sun in summer it must have been near the sun in winter, and therefore above the average warmth; and when there was thus a mild winter in the hemisphere where the glacial climate prevailed, there must have been a hot summer in the opposite hemisphere, and consequently great evaporation of water, part of which would fall in rain or snow on the glaciated hemisphere, and swell its rivers and torrents. It is true that the total quantity of heat which the earth receives from the sun in a year is but very slightly affected by any variation in the eccentricity of the earth's orbit; but the greater the eccentricity the

more will the heating effect of the sun's rays be crowded into a few months of the year, and this will cause more evaporation, and consequently more rain and snow, than if the heating effect were equally distributed over the year.

The fact—supposing it proved, and there appears to be strong evidence of it—that the flow of water in European river-beds was once greater than it is at present, and the excavating action of the streams consequently more energetic, suggests the interesting question whether geological change has always, throughout past ages, gone on as slowly as it does now. No man of any scientific knowledge now doubts that the nature of geological changes, and the causes by which they are effected, are the same in the present age that they have been ever since the earth became a solid globe. In other words, it is universally admitted that there has been no change in the laws and forces of nature, and that the agencies which have raised up mountain-chains and deposited strata of miles in thickness, are no other than those which are still at work in the world around us. But, in asserting this, it appears to be often implied that geological action and geological change never went on much more rapidly than they do now. But this is not proved, and in my opinion it is contrary to the evidence. As I have remarked, there are two sets of agencies of geological change—the internal, to which upheavals, earthquakes, and volcanic eruptions belong; and the external, or oceanic and atmospheric. Now, of these two I maintain that the internal forces are declining in energy, and the external ones are not constant, but fluctuate from age to age. The internal forces cannot be constant, because, as I have endeavoured to show, they depend on the slow cooling of the earth; and this cannot go on uniformly from age to age, but, on the contrary, must be slower in each successive age, because the more a body has cooled the more slowly the remainder of the cooling process will go on. And the external forces are not constant, but are liable to periodical changes, depending on changes of climate. Glacial periods must be periods of exceptional activity of change in physical geology, because of the great power of glaciers in wearing down mountains and excavating valleys; and also, as I have tried to prove, because glacial periods are periods of exceptionally great rain and snow-fall, and therefore of unusually

energetic action in the wearing down of the land and the excavation of river-beds. It is also not at all improbable that the sun has grown sensibly cooler since geological time began. If this is true, evaporation and rain-fall must have diminished, and this would lower the energy of geological action. But the diminution of the sun's heat is a subject on which we scarcely have the data to speculate. In my opinion, however, all approximate calculations of the length of geological periods from the rate of geological change, as it is observed to go on now, are altogether misleading. Geological time may have been much shorter than many geologists are apt to suppose. It has been estimated by Sir William Thomson, from the mathematical laws of the cooling of masses, that it cannot be more than about a hundred millions of years since the earth was sufficiently cooled down to bear life on its surface ; and from the point of view of merely physical geology, this appears to me to present no difficulties whatever; though it is, no doubt, a great difficulty in the way of Darwin's theory of the origin of species, which would derive all living beings, up to the elephant and man, from the simplest animalcules, by no other agency than the "selection among spontaneous variations," by which the pouter and the tumbler have been obtained from the original stock of rock-pigeon. For such a process, a hundred millions of years are much too short a period; but then I would add that eternity would not be long enough.

In the beginning of this address I spoke of it as a highly probable hypothesis that the solar and the entire stellar system have been formed by the condensation of a nebula. This theory was formerly often denounced as irreligious, as if the nebula could somehow supersede necessity of a Creator. This was a mere stupidity; but it is true, though not very obvious, that the nebular theory, and the entire conception of force with which it is connected, so far from excluding, demand creative power. Philosophers may have formerly dreamed of a succession of changes without end and without beginning ; but we now see this to be impossible under the laws of nature. The nebula has transformed itself into stars and planets ; but the stars and planets cannot transform themselves back into a nebula. The stars and planets have originated in a nebula ; but in what did the nebula originate ? It must have been created. "The things which are seen were not made of things which appear."

November 27th, 1872.

Joseph John Murphy, Esq., the President of the Society, in the Chair.

A Paper was read by Professor J. D. EVERETT, M.A., D.C.L.,

On Mirage.

The name of Mirage is applied to certain illusory appearances due to excessive bending of the rays of light in their passage through the atmosphere. These appearances are by no means uniform.

Sometimes, especially in hot countries, the observer loses sight of the ground beyond a certain distance from his position, and sees in its stead, what looks like a sheet of water, either calm or with movements resembling waves ; and if any distant objects are sufficiently lofty to be seen above this apparent lake, their images are seen beneath the objects themselves, inverted as if by reflection in this imaginary water. The dry and hot soil of Egypt is famous for the production of this form of the phenomenon. It is also mentioned as of frequent occurrence in the plains of Hungary, in the plain of La Crau in the South of France, and in the fen districts of England when dried up by the summer heat. It is also common in Australia. The Deputy Surveyor-General of South Australia once reported the existence of a large inland lake, which on further examination turned out to be nothing but a mirage.

Another class of appearances are known (especially among nautical men) under the name of looming. Distant objects are said to loom when they appear abnormally elevated above their true positions. This abnormal elevation not unfrequently brings into view

objects which in ordinary circumstances are beyond the horizon. It is also frequently accompanied by an appearance of abnormal proximity (though this may perhaps be rather a subjective inference from the unusual elevation and clear visbility of the objects than a separate optical characteristic), and it is further accompanied in many, though not in all cases, by a vertical magnification, the heights of objects being many times magnified in comparison with their horizontal breadths, so as to produce an appearance resembling spires, pinnacles, columns, or basaltic cliffs. Some beautiful descriptions of these latter appearances, with illustrative plates, are given in Scoresby's "Greenland," the objects thus magnified being icebergs; and a very full and interesting account of the phenomena of mirage, as observed in high latitudes, will also be found in the "Arctic Regions," of the same author.

It is usually across water that looming is observed; and as a surface of water stands naturally in contrast with a sandy desert or a surface of parched land, so also the optical effects produced are, in a manner, opposite. The inverted images which are often presented in looming are not beneath the object, as in the case of mirage on dry land, but above it, as if formed by reflection in the sky. The only examples that I have myself seen of mirage were of this kind. They were seen across sheets of calm water, the hills on the other side being seen with fictitious hills upside down resting on the tops of the real hills. In rare instances, two or even three of these images are seen one above another, vertically over the real object; but these multiple images are usually too small to be seen without the aid of a telescope—the objects whose images they are being so distant as to appear mere specks to the naked eye.

There is always more or less of change observable in the images formed by mirage, and the changes are greatest and most sudden when the images are most distorted as compared with the true forms of the objects. The appearances also change with the height of the observer's eye. Looming is seen to the greatest advantage from an elevated position, such as the mast head of a ship. The mirage of dry land is sometimes visible at any moderate height, but in other cases—especially in countries which are not very hot—the range of height from which it is visible is extremely limited. A very fine

mirage, recently observed in the fen districts, was only seen when the observer was on the top of the marsh wall. But this case seems to have been peculiar. It was accompanied by the further peculiarity that a strong wind was blowing—the general rule being that mirage is only seen in calm weather. Observers of mirage on the sands of Morecambe Bay, and of the Devonshire coast, state that it could frequently be only seen by stooping.

Mirage is seldom seen in winter. The hot shining of the sun seems to be an invariable antecedent; and this is true even of the Polar Regions, where Captain Scoresby attributes the phenomenon to "the rapid evaporation which takes place in a hot sun from the surface of the sea, and the unequal density occasioned by partial condensations, when the moist air becomes chilled by passing over considerable surfaces of ice."

Time will not allow me to do much in the way of quoting the very numerous records which exist. Scoresby's accounts alone would almost suffice to occupy the evening, and I would again refer to them as models of accurate observation and effective description. I will content myself with quoting nearly in full the account of a mirage observed at Hastings, and neighbouring parts of the south coast of England, in 1798, as given in the Philosophical Transactions for that year, the narrator being Mr. Latham, F.R.S.

"On Wednesday last, July 26, about five o'clock in the afternoon, whilst I was sitting in my dining-room at this place (Hastings), which is situated upon the parade, close to the sea-shore, nearly fronting the south, my attention was excited by a great number of people running down to the sea-side. Upon enquiring the reason, I was informed that the coast of France was plainly to be distinguished with the naked eye. I immediately went down to the shore, and was surprised to find that, even without the assistance of a telescope, I could very plainly see the cliffs on the opposite coast, which at the nearest part, are between 40 and 50 miles distant, and are not to be discerned from that low situation by the aid of the best glasses. They appeared to be only a few miles off, and seemed to extend for some leagues along the coast. I pursued my walk along the shore to the eastward, close to the water's edge, conversing with the sailors and fishermen on the subject. They, at first, could not be persuaded of the reality of the appearance; but they soon became so thoroughly convinced, by the cliffs gradually appearing more elevated and approaching nearer, as it were, that they pointed out and named to me the different places they had been accustomed to visit, such as the Bay, the Old Head or Man, the Windmill, &c., at Boulogne, St. Valéry, and other places on the coast of Picardy, which they afterwards confirmed when they viewed them through

their telescopes. Their observations were, that the places appeared as near as if they were sailing at a small distance into the harbours.

"Having indulged my curiosity upon the shore for near an hour, during which the cliffs appeared to be at some times more bright and near, at others more faint, and at a greater distance, but never out of sight, I went upon the eastern cliff, which is of a very considerable height, when a most beautiful scene presented itself to my view; for I could at once see Dungeness, Dover cliffs, and the French coast, all along from Calais, Boulogne, &c., to St. Valéry, and, as some of the fishermen affirmed, as far to the westward as Dieppe. By the telescope, the French fishing boats were plainly to be seen at anchor, and the different colours of the land upon the heights, together with the buildings, were perfectly discernible. This curious phenomenon continued in the highest splendour till past eight o'clock, ... when it gradually vanished. The day was extremely hot, ... not a breath of wind was stirring the whole of the day. . . . . A few days afterwards I was at Winchelsea, and at several places along the coast, where I was informed the above phenomenon had been easily visible.

"I should also have observed that when I was upon the eastern hill, the cape of land called Dungeness, which extends nearly two miles into the sea, and is about sixteen miles distant from Hastings, in a right line, appeared as if quite close to it, as did the fishing boats and other vessels which were sailing between the two places. They were likewise magnified to a great degree."

I have stated that the phenomena which constitute Mirage are due to the bending of rays of light in the atmosphere, and I now proceed to point out the principles by which this bending is governed.

My esteemed colleague, Dr. James Thomson, has greatly contributed to the clearness of our knowledge, as regards the disturbing effect of the atmosphere upon the direction of a ray of light. He has recently published an investigation,* which, to say the least, is simpler and more satisfactory than any before given, of the precise law which determines the curved path of a ray through the air.

Referring you for the details to the last chapter but one of my own recently published edition of Deschanel's Natural Philosophy, I will merely say, that, when a ray is passing through a portion of air which is not equally dense all round it, it is deflected towards the side on which the density is greatest; and that the sharpness of the curvature, as measured by the change of direction for a given length of the ray, is directly proportional to the rate at which the density varies along the normal. Strictly speaking, I ought, instead of "density," to have said "absolute index of refraction, diminished by

* British Association Report, 1872, p. 41.

unity;" but experiment has shown that the difference between these two statements, when there is no substance in question except air and aqueous vapour, is quite insignificant.

Supposing the stratification of the air to be strictly horizontal, it follows that a ray travelling vertically will not be bent at all, since there is no variation of density in the direction of its normal; and, of all rays which traverse the same point, those which are horizontal will be bent the most, because the whole change of density is normal to them, and has a direct tendency to bend them downwards. For rays which are *nearly* horizontal, the curvature will be very nearly the same; and, as it is by such rays that we see the images which constitute Mirage, the maximum bending of atmospheric rays is available for the explanation of the phenomena. In the average state of the atmosphere, the curvature of rays which are horizontal, or nearly so, is about $^1/_5$ or $^1/_6$ of the curvature of the earth's surface; though it is to be remarked, by way of caution, that the connection between these two curvatures is merely accidental; the curvature of the earth is not the cause, nor even a partial cause, of the curvature of rays.

Other things being equal, the curvature of rays should be greater in cold than in warm air, and greater with high than with low barometer; but these are not the *principal* modifying elements. The circumstance which it is most important to know, at any time, in order to predict the degree of curvature, is the rate at which the temperature changes with the height. The average change is a fall of about $^1/_{300}$ of a degree Fahr. per foot of ascent. A fall of $^1/_{53}$ of a degree per foot of ascent would make the air equally dense at all heights, and would cause rays to travel in absolutely straight lines. A more rapid fall than this would render the air aloft denser than that below, and would cause rays to bend up instead of down. The existence of denser, and therefore heavier air aloft, is obviously incompatible with stability of equilibrium; but unstable equilibrium may endure for a time, even under statical conditions; and when there is a powerful cause at work, tending to raise the temperature of the lower strata, it is quite conceivable that the lower air may be heated faster than it can get away (if I may be allowed a somewhat loose expression); so that, although there is a perpetual diffusion going on, the heated air ascending, and cooler air from above taking its place, there is,

nevertheless, a difference of temperature perpetually maintained, exceeding $^1/_{50}$ of a degree per foot. The circumstances under which the Egyptian form of mirage is observed are precisely such as are fitted to produce this state of things. A fierce sun scorching the parched ground, while the air is excessively transparent to his rays—flatness of surface, eminently conducive to the maintenance of unstable equilibrium—and absence of wind—such are the conditions under which this form of mirage appears. On the other hand, if the decrease of temperature upwards is slower than usual, the ordinary downward bending of rays will be increased, and if any physical cause, such as warm winds commencing aloft, before they are felt at the earth's surface, produces a reversal of the ordinary distribution of temperature, so that there is an *increase* upwards, instead of a decrease, this change will favour the downward bending of rays, which will, accordingly, be exaggerated ; for the lower air being not only under greater pressure, but being also colder than the upper air, will for a double reason be denser.

Capt. Scoresby states that "the curious refractions of the atmosphere in the polar regions are most frequent on the commencement or approach of easterly winds," and he elsewhere states that easterly and southerly winds are mild.

An increase of temperature upwards, at the rate of about $^1/_{16}$ of a degree Fahr. per foot, would make the curvature of rays equal to that of the earth, so that a ray might encircle the globe. Any increase in the downward bending of rays increases the range of vision, by enabling them to bend round the horizon, which previously limited the view. The visible effect is precisely the same as if the convexity of the surface of the earth were diminished. And not only will objects which were previously beyond the horizon be brought into view, but objects which were previously visible near the horizon will become plainer, inasmuch as the rays by which they are seen will not pass so close to the intervening surface as before, but will traverse a higher portion of the air, which is less liable to be obscured by impurities.

Having now laid down the first principles, to which all effects of atmospheric refraction must be traced, we will proceed to some more particular applications.

I have recently been considering the question—what must be

the law of density (or, more strictly, of refractive index) in a horizontally stratified atmosphere, in order that images formed by mirage may be perfectly sharp; and some of the diagrams before you (Pl. I.) will serve to explain the results which I have obtained.

First.—Neglect the curvature of the earth, and suppose the surface of uniform index to be plane; then the law required is as follows:—There must be a plane of maximum index, at which the rate of variation of index with height must be zero; and as we ascend or descend from this plane of reference the rate of variation of index must continually increase in direct proportion to the distance. The rate must also be the same at equal distances above and below this plane of reference. The curvature of a horizontal, or nearly horizontal ray, will thus be simply proportional to distance from the plane of reference, and the bending from either side will be towards this plane. Rays may accordingly pierce this plane (which is indicated by a dotted line in figs. 1, 2) again and again, any number of times, and every time that they do so they will undergo a reversal of curvature. The curvature at the point of crossing will be nil. The curves described will be what are called "harmonic curves," or "curves of sines," such as are represented in figs. 1, 2; subject to the restriction that we have only to do with rays which are so nearly horizontal that the cosines of their inclinations may be treated as unity. The distance between consecutive intersections will be the same for all the curves, and is easily computed in terms of the constant which enters into the expression for the variation of index. A pencil of rays diverging in the same vertical plane from a point in the plane of reference, will thus converge accurately to another point in the plane, as represented in fig. 1. Such a pair of points may be called principal conjugate foci. But this property of accurate convergence is not confined to pencils proceeding from points in the plane of reference. The same property attaches to pencils diverging from any point whatever; the conjugate focus being always a point at the same distance on the other side of the plane of reference, and the horizontal distance between the two being the same as in the preceding case. This property is illustrated by fig. 2.

It is obvious that the conjugate foci will occur not in pairs merely, but in sets of unlimited number; that is to say, rays proceeding

originally from any one point will converge in succession to an indefinite number of other points, which will be alternately on opposite sides of the plane of reference. As every point on the surface of an object will thus have its conjugates, we shall have a succession of images of the object. The first image will be upside down, the second erect, and so on alternately. They will be what are technically called "real" images, and will be precisely equal and similar (except as regards inversion) to the object itself. It is of course to be understood that the action here described is confined to one dimension only, resembling that of a cylindrical, rather than of a spherical lens. Rays are bent to and from the plane of reference, but in no other direction. This theoretically simple case is so important for the light which it throws upon the possibilities of atmospheric refraction, that we shall examine some of its consequences a little further.

What will be the appearance presented to the eye of an observer in any given position?

The case differs greatly from that of the images in ordinary optics, where the refracting instruments are glass lenses, and the eye sees the image by means of rays which travel in straight lines.

In the case now before us, the observer will in general see a virtual image, differing considerably, both in size and direction, not only from the object itself, but also from any one of the real images. The apparent direction of any point of the visible image is of course determined by drawing a tangent to the ray which enters the eye* (fig. 6, 7); and the visual angle, or, as we may call it, the apparent size of the object, will be the angle between two of these tangents. If the eye is a little distance (say a few feet) behind one of the real images, enormous magnification will be produced, for the image has the same linear height as the object, and is seen from a distance of a few feet, instead of from the real distance of the object, which we may suppose to be a few miles. We shall thus have enormous magnification of the vertical diameter of the object; while the horizontal diameter will of course be only of the natural size, since the rays have undergone no bending except up and down. An object whose breadth is equal to its height will thus be magnified into

* The letter E, in all the figures, denotes the position of the observer's eye.

a tall column. Some appearances of this kind, copied from Scoresby's "Greenland," are represented in the first two figures of Plate II. The following is Scoresby's description (Greenland, p. 96) :—

"Hummocks of ice assumed the forms of castles, obelisks, and spires, and the land presented extraordinary features. In some places the distant ice was so extremely irregular, and appeared so full of pinnacles, that it resembled a forest of naked trees; in others it had the character of an extensive city, crowded with churches, castles, and public edifices."

Again, on page 163 of the same work :—

"At one period the phenomenon was so universal that the space in which the ship navigated seemed to be one vast circular area, bounded by a mural precipice of great elevation, of basaltic ice."

The magnificent columns which constitute a portion of the wonders of the Fata Morgana, at the Straits of Messina, are in like manner to be attributed to vertical magnification. And an appearance of the same kind, known as "the merry dancers," is often seen by boatmen off the Giant's Causeway, in looking over the Skerries towards Portrush.

If we could have density distributed symmetrically round an axis, instead of on the two sides of a plane, we might of course have magnification without distortion. But we can scarcely conceive of any arrangement at all resembling this existing in the atmosphere.

It is further to be remarked, that the apparent distance of one of our columnar images from the observer's eye is an ambiguous quantity. If judged by left and right displacement, it is the real distance of the object. If judged by up and down displacement, it is much less, being approximately the distance of the real image.

We will now modify our imaginary distribution of density in such a way as to adapt it to a convex earth. To do this we have merely to bend our diagram to the earth's curvature.

The result is shown in fig. 3, where the dotted line represents a level line coincident with a stratum of equal density in the earth's atmosphere, and, like any other level line, partaking of the general curvature of the earth. It is of the same length as the dotted line in our first diagram, and ordinates (offsets), equal to those in fig. 1, are laid off from it, in normal directions, at the same number of equidistant points. The curves thus obtained possess all the properties, as regards foci and images, which we have pointed out as belonging to

those of figures 1 and 2 ; and we can now afford to dispense with the difficult physical postulate of a diminution of density downwards from the plane of reference. One of the rays in fig. 3 is everywhere concave downwards, and, therefore, the air which it traverses increases in density downwards.

If we suppose the law which gave figs. 1 and 2 to hold only on one side of the plane of reference, while on the other side of this plane the density is uniform, we shall have conjugate foci for points in the plane of reference, but for no other points. The conjugate foci will themselves be in the plane of reference, and the distance from any point to its conjugate will be constant. Rays coming to the plane of reference from the side on which the density is uniform, will be bent round so as to meet the plane of reference again at a constant distance in advance of the points at which they entered, and the angle of emergence will be equal to the angle of incidence. More generally, whenever there is a layer of air in which the density diminishes very rapidly from one side to the other, while the density elsewhere is comparatively constant, rays entering this variable stratum from the denser side will (if their inclinations to the stratum are not too great) bend round in it and emerge from it again on the same side, as in figs. 4 and 5. In fig. 4 the dotted line may be supposed to represent a plane, beneath which the density diminishes more and more rapidly down to the ground (which is represented by the shading). In fig. 5 the shading represents a stratum in which the density diminishes rapidly in ascending, the diminution being most rapid at the middle of the stratum. In both cases, the appearance presented to an eye at E will be nearly the same as if the rays had been reflected from a plane mirror behind and parallel to the stratum, I say *nearly* the same, because the position of the equivalent plane mirror will not be precisely the same for rays at different inclinations to the stratum. Objects will thus be seen inverted, without being necessarily either magnified or diminished. Fig. 4 is intended to illustrate the mirage of the desert, and fig. 5 to illustrate the formation of inverted images in looming. In fig. 4, tracing the three rays backwards from the observer's eye at E, the lowest of the three at the eye end is bent up just sufficiently to prevent it striking the ground, and then goes away to the sky, so that he will see the sky as if reflected

from the ground. The second ray does not pass quite so near the ground, and it goes away to a lower part of the sky. The third ray follows a similar course, not descending quite so near the ground, and going off in a direction more nearly horizontal. We may suppose it to be terminated by a tree, hill, or other tall object, which will accordingly be seen reflected beyond the image of the sky.

Rays a little higher than this will escape the upward bending which has produced these effects, and which is due to the action of a comparatively thin stratum of air near the ground. The same objects which have been seen apparently reflected by the ground, will thus be also seen erect in their true positions. The relation between the appearances of the true and the reflected objects is almost precisely the same as if there were a sheet of water occupying the place of the ground; and the flickering of the air as the hotter and colder currents ascend and descend will bear a close resemblance to waves ruffling the surface of the imaginary lake.

The earliest explanation of mirage, I believe, on record is that of Monge [Ann. de Chim. xxix., 207], one of the savans who accompanied Bonaparte in his expedition to Egypt. The following is the passage in the Annales, which purports to be an abstract of a memoir read at a meeting of the Institute, held at Cairo :—

"At sea it often happens that a ship seen from afar appears to be floating in the sky and not to be supported by the water. An analogous effect was witnessed by all the French during the march of the army across the desert. The villages seen in the distance appeared to be built upon an island in the midst of a lake. As the observer approached them, the boundary of the apparent water retreated, and on nearing the village it disappeared, to recommence for the next village. Citizen Monge attributes this effect to the diminution of density of the inferior layer of the atmosphere. This diminution in the desert is produced by the augmentation of temperature, which is the result of the heat communicated by the sun to the sands with which this layer is in immediate contact. . . . In this state of things the rays of light which come from the lower parts of the sky, having arrived at the surface which separates the less dense layer from those which are above, do not penetrate this layer; they are reflected, and thus form in the eye of the observer an image of the sky. He thus sees what looks like a portion of the sky beneath the horizon, and it is this which he takes for water."

The only objection which I think can be taken to this explanation of Monge, is that it seems to imply not a curvature, but an angle in the course of the rays, just as in the case of what is called *total*

internal reflection at the bounding surface of a piece of glass when the angle of incidence exceeds the critical angle.

Now, the formation of an angle (even a very obtuse angle), in a ray, would require a perfectly sharp transition from one degree of density to another, instead of the gradual transitions which are more in accordance with our knowledge of the properties of air. We have shown that no such harsh supposition is necessary.

As to the propriety of applying the name *reflection* to an action such as that represented in figs. 4 and 5, it is perhaps just as proper as the application of the name *refraction* to the bending of rays which takes place in the atmosphere, the term refraction being primarily employed to denote bending not into a curve but into an angle, at places where a ray passes by a sharp transition from one medium into another.

The shaded region in fig. 5 represents a portion of the atmosphere in which there is a rapid diminution of density upwards. We may regard it as the region of intermixture, between two portions of air, which differ greatly from each other in density, the denser portion extending downwards to the earth without any very rapid changes, and the rarer portion extending in a similar gradual manner upwards to the clouds. If these two dissimilar portions of air have been only recently brought into proximity, as by the commencement in the upper regions of a wind from some warm quarter, we should expect to find a border tract, where the transition would be unusually rapid, the border tract itself being indefinite in its boundaries above and below, and the transition being most rapid in its central parts. The figure has been drawn to suit these suppositions, and it shows, besides two rays which have been reflected, a third ray which has barely been able to get through.

Any one who is fresh from the study of optics will be at once struck with the analogy between the behaviour of these rays and of rays passing or endeavouring to pass from water into air; and the analogy is quantitative, as well as qualitative. For

1. As regards those rays which get through, it can be shown that the total change of direction for a ray of a given incidence, depends only on the densities above and below the region of intermixture, and is altogether independent of the thickness of this intermediate region. This is on the assumption that the surfaces of equal

density are parallel planes. If, as in the case of air, the extreme relative index of refraction differs but little from unity, the change of direction is proportional to the tangent of the angle of incidence, and is equal to the product of this tangent by $\mu - 1$, μ denoting the relative index. This is the law which governs the refraction of rays from the heavenly bodies, in traversing the earth's atmosphere; except when these bodies are so near the horizon that the curvature of the earth and its atmosphere produces a sensible effect.

2. As a consequence of the preceding point of agreement, the critical angle which separates those rays which get through from those which are turned back, is also dependent solely on the comparison of the two extreme densities, that is on the value of the relative index of refraction.

In the comparatively rare instances in which several inverted images of the same object have been seen in the sky, as in the third figure of Plate II., which represents a telescopic appearance observed by Scoresby, a possible explanation may be found in irregularities of form in the stratum of intermixture, which instead of being truly horizontal, may be tilted to slightly unequal degrees in different parts, so that it acts, not like *one* plane mirror, but like several plane mirrors slightly inclined to each other. Another, and I think more probable explanation, is the existence of more than one layer of rapid transition.

Whenever an image is inverted, the rays by which it is seen must have crossed; that is to say, the two rays which come to one and the same point of the eye from two neighbouring points of the object, must have crossed each other once on the road. If they have crossed twice, the image will be erect; if three times, inverted; and so on.

When all the rays are circular arcs, and their curvatures are all equal, it will be impossible for them to cross, and hence no inverted image can be formed; neither can there in this case be any increase or diminution of apparent size. This is evident from the consideration that a diagram indicating the paths of such rays to the eye, only needs to be bent with a curvature equal and opposite to that of the given rays, in order to render all these rays straight; and such bending will not affect the sizes of the images.

If, however, our rays are circular arcs of unequal curvatures, we

may have crossing, and may also have magnification or diminution. It is obvious, from figs. 6 and 7, that to give a magnified virtual image without crossing, the upper ray must be bent downwards more than the lower one; and that if the lower ray be bent down more than the upper, the image seen will be diminished.

These rules must be borne in mind, in attempting to explain that very common form of mirage in which distant objects are greatly magnified in their vertical dimensions without any other change. Fig. 4 may help us to understand how this magnification arises. If we suppose an object to travel along between two of the rays which proceed from the eye, it is clear from the diagram that the object will begin to be sensibly magnified as it enters the region of rapid change, and the magnification will increase as the object nears the intersection of these rays, at which point it becomes infinite, which practically means that, if placed at this point, it will give rise to an appearance of the greatest possible confusion. As it travels further away between the same two rays, it will begin to be again recognized by a highly magnified and inverted image. One of the commonest, I believe the commonest form of mirage in Australia, is one in which small bushes at a distance are magnified into trees; and I believe the foregoing to be the correct explanation.

The magnification over water which gives rise to the architectural columns of the Straits of Messina, and of the Polar Regions, is more probably to be explained by the action represented in fig. 6, the region of most rapid change of density being at a height somewhat greater than that of the top of the object, so that the top is greatly elevated by refraction, while the bottom remains nearly in its true place.

The quasi reflection, illustrated in figure 4, may be produced artificially by carefully depositing alcohol or methylated spirit, to the depth of about an inch, upon water contained in a glass vessel with plane parallel sides. The spirit, though lighter, has a higher index of refraction than the water; and at the place of intermixture of the two liquids, we have a gradual but very rapid diminution of index in descending. On bringing the eye close to the vessel, and looking obliquely downwards towards this part of the liquid, very perfect inverted images will be seen. The field of view afforded by this

arrangement is, however, extremely limited; and a much finer effect is obtained by the arrangement now before you, in which three liquids are employed, the middle one having the highest index of refraction, while its specific gravity is intermediate between those of the other two.

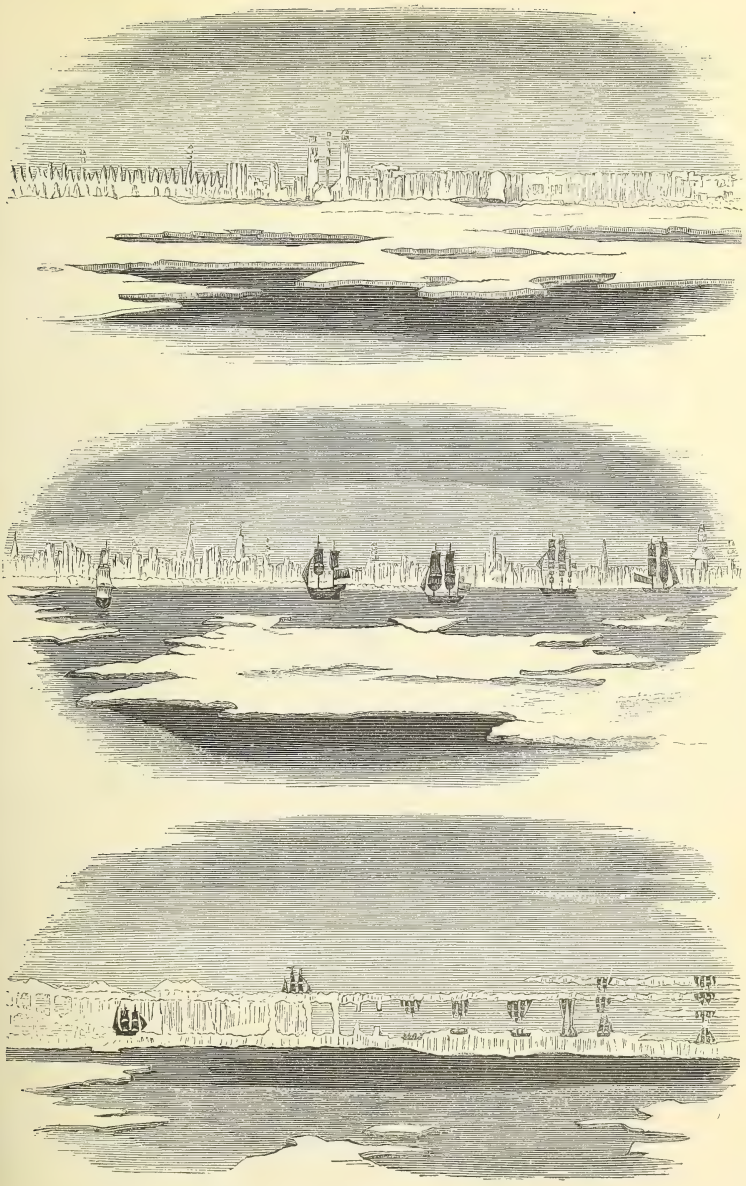
The three liquids are—

1. A strong solution of alum at the bottom.
2. Pure water at the top.
3. Scotch whisky mixed with enough sugar to make its specific gravity intermediate between those of the other two liquids. It is introduced last by means of a pipette.

Plate III. represents the appearance which this arrangement afforded, when set up at a window of my house looking towards the mountains.

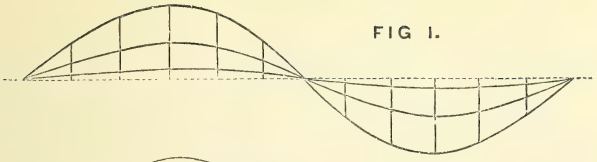
Every object in the landscape was tripled, the three images being seen at once; and the vertical breadth of the strip of landscape thus tripled at one view, extended from the top of the hills down to the houses on the Lisburn Road. The figure only shows the more conspicuous objects. When the sun was shining on the front of the row of houses represented, which was nearly half a mile distant, I was able to see distinctly the chimneys and windows, and even to see whether the blinds were up, down, or half-way down. It was easy to fancy that the inverted trees and houses were the reflections of the upper ones in water. But a much more striking effect, as of water, was at the place which is left white in the figure, at the junction of the middle and lower image. This had all the appearance of a calm bay or lake glistening in the sunshine. There are only two natural objects to which this peculiar glistening belongs, with brightness far surpassing that of all the dry and solid parts of a landscape. One of these is water, and the other is the sky. A bit of sky has in fact been trapped between two portions of land; and it is a similar trapping of sky in the midst of dry land, that produces the irresistible impression of a lake of water in the mind of the traveller in the desert. The middle image is probably formed by rays which have taken a path something like those in Figs. 1, 2, and 3. The highest and lowest image are formed by rays which have only been bent one way.

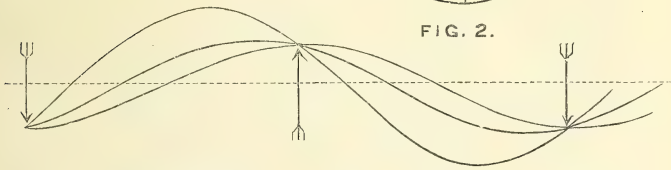
The arrangement of three liquids just described, which was sug-

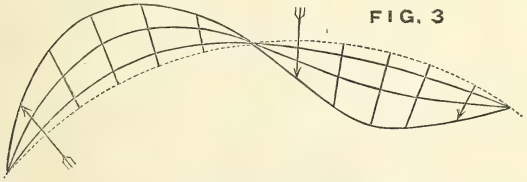


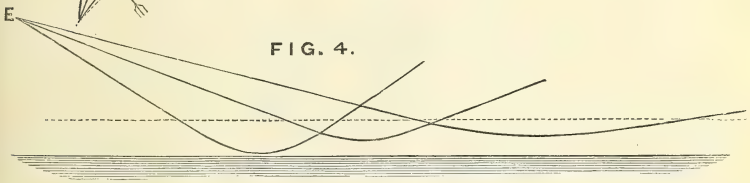
MIRAGE.—PLATE II.

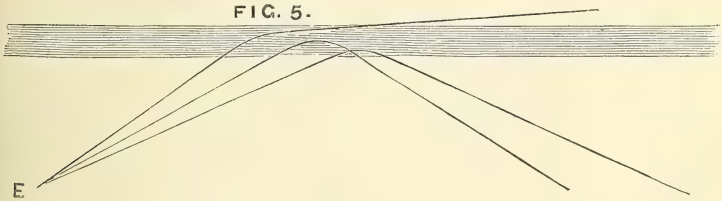
BRITISH MUSEUM
NATURAL HISTORY.

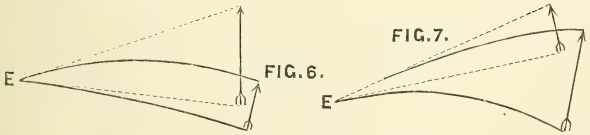






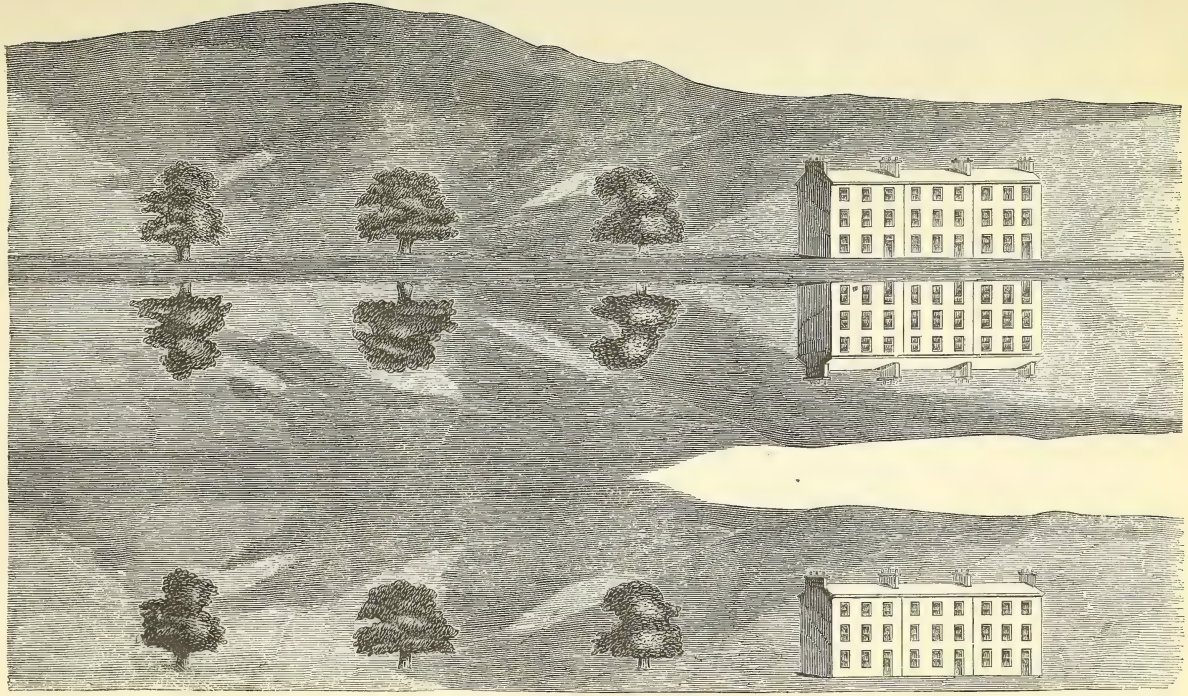






MIRAGE.—PLATE I.

BRITISH MUSEUM
NATURAL HISTORY



MIRAGE.—PLATE III.

BRITISH MUSEUM
NATURAL HISTORY

gested to me by Professor Clerk Maxwell, is extremely effective, but requires much delicacy in its preparation to ensure success.

Triple images of objects below the level of the vessel may be obtained by employing only the two first-mentioned liquids—alum water and pure water, or strong brine and pure water. A little gentle stirring is advantageous whichever arrangement be employed, a glass rod being inserted vertically, passed a few times slowly round the circumferential portion of the liquids, and then withdrawn.

With the two-liquid arrangement I have obtained three spectra, the middle one inverted, by employing as object a horizontal slit in the shutter of a dark room ; and very brilliant colour effects were obtained by bringing the eye to the conjugate focus of the slit. A screen held at this conjugate focus, which was at first close behind the vessel of liquid, and slowly receded day by day, received an image of the slit very similar to that which would be formed by a cylindrical lens.

In order to see the three images (or spectra), it was necessary to hold the eye behind the conjugate focus. When it was held in front (that is nearer to the vessel), only two images were seen, sometimes only one, the middle or inverted image being always wanting.

A similar lengthening of focus day by day was observed with the three-liquid arrangement, which would doubtless yield similar colour effects.

11th December, 1872.

Joseph John Murphy, Esq., F.G.S., President of the Society, in the Chair.

A Paper was read by PROFESSOR HODGES, M.D., F.C.S., Queen's College,

On some New Methods of Chemical Analysis.

Professor Hodges stated that the important results which have been derived from the observations of inquirers into the laws of diffusion, and the influence which the phenomena included under this designation exercise on so many of the changes which are constantly taking place in the materials of the globe and in the organisms of plants and animals, had led him to believe that a notice of the facts which have been ascertained in this department of physico-chemical inquiry would be found interesting, especially the application of these facts to chemical analysis and industrial processes. The lecturer proceeded to demonstrate these facts by explaining how the celebrated Priestley was led to the discovery of the diffusion of gases; he also explained Dr. Dalton's views of the subject. He stated that it was to the late Mr. Graham, of the Royal Mint, that we are indebted for the full investigation of the laws which govern the diffusion of gases, and performed several beautiful and novel experiments, which he had devised for the occasion, to illustrate these laws. Several useful applications of the law of gaseous diffusion have already been made, among which he described the invention of an apparatus by Mr. Ansell for the detection and estimation of explosive gas in coal mines, thereby preventing those terrible accidents which are occasionally occurring: several forms of Mr. Ansell's apparatus have been constructed, but by far the most elegant and useful of these contrivances is a small aneroid

barometer, the case of which is made perfectly air-tight, but the interior of which may be placed in communication with the external air by opening a small screw. The brass back of this barometer is replaced by a tin plate of porous earthenware, and may be covered with a brass cap placed on a hinge. Under ordinary circumstances the screw remains open, but when it is required to test the gas in a mine the screw is closed and the cap removed from the porous plate; immediately diffusion takes place, and the pressure increasing causes a corresponding movement of the hand of the barometer. In about 45 seconds the maximum effect is produced, when the position of the hand indicates by means of a vernier the per centage of mine gases present.

The lecturer, after explaining the views of several experimenters on the diffusion of gases, passed on to the consideration of the laws which have been found to influence the diffusion of liquids of different densities. The tendency of liquids to intermingle, even though their molecules possess great difference in density, is familiarly known in the case of the greater number of liquids: this is simple diffusion between liquids; but in the case of saline solutions the investigations which have been made have offered some exceedingly curious results. Mr. Graham, in his early investigations of this subject, was led to observe that, whilst solutions of salts were in general distinguished by diffusing with considerable rapidity, the albumen of the egg and certain substances which, like it, are distinguished by the absence of crystalline form, exhibited comparatively slight diffusive mobility; and the difference between the diffusibility of these substances and of saline matters suggested to him a delicate method for their separation in analytical investigations, as it was found that the diffusibility of the salts was not interfered with by the admixture with albumen, but that they diffused out from it just as readily as when dissolved in pure water. On continuing his investigations, Mr. Graham found that a large number of substances like albumen, such as gum, tannin, and animal and vegetable extractive matters, and even many inorganic substances, like gelatinous silica and hydrated alumina, possessed a very slight diffusive mobility as compared with saline matters; so that as we are accustomed to divide bodies into two classes, as volatile and non-volatile, we may classify them also according to the degree

of diffusibility which they possess in the liquid state. Substances which belong to the class, distinguished by diffusibility, are generally crystalline, free from viscidity, and sapid. Mr. Graham proposed to call such substances crystalloids, and those which are distinguished by low diffusibility, colloids; gelatine being regarded as the type of the colloid class of bodies. In the course of his experiments, Mr. Graham found that by employing a colloid for the crystalloid to diffuse into, the diffusion proceeded without any abatement of velocity, and that a piece of letter paper which is sized by means of starch, serves as a means of effecting a complete separation of the crystalloids of a solution from the colloidal substances which may be mixed with them. To this separation of substances, by means of a septum of gelatinous matter, Mr. Graham has given the name of dialysis.

In 1857, Mr. De la Rue introduced a vegetable parchment, made by immersing ordinary paper for a few seconds in dilute sulphuric acid, when it undergoes a singular alteration in its texture, and is converted into a material closely resembling parchment, which has been found to provide us with a most convenient colloid septum, through which crystalline bodies can diffuse themselves, while colloids are unable to do so. Professor Hodges then described the various forms of apparatus which have been contrived, in which parchment paper is employed in dialysis.

With respect to the action of the septum in this process, Mr. Graham's explanation is that crystalloids possess the power of appropriating to themselves the water of a gelatinous septum, and are thus able to obtain a medium for diffusion. The dissolved colloids, possessing only a most feeble affinity for water, are unable to separate that liquid from the septum, and cannot therefore penetrate the membrane, so as to open the door for their own passage outwards by diffusion.

The process of dialysis has been turned to account, both by the chemist and the manufacturer; by the former for the separation of crystalloidal substances, like arsenic, and the other poisonous metallic compounds, from the organic colloidal substances which usually interfere so much with the action of reagents in toxicological investigations. For industrial processes it has been taken advantage of in France by such men as Dubrunfaut, who by its means has got over one of the

greatest difficulties of sugar manufacture—namely, the separation of the crystallizable from the uncrystallizable sugar ; and, in Scotland, by a scientific manufacturer, Mr. Whitelaw, of Glasgow, who has patented an ingenious application of it to render available for food the valuable portion of meat usually lost in the operation of salting.

15*th January*, 1873.

ROBERT YOUNG, Esq., C.E., in the Chair.

A Paper was read by ROBERT O. CUNNINGHAM, M.D., F.L.S.; Professor of Natural History, Queen's College, Belfast,

ON THE PHYSICAL FEATURES AND NATURAL HISTORY OF SOUTHERN PATAGONIA AND TIERRA DEL FUEGO;

From Personal Observations made during the years 1866-69.

A GLANCE at a map of South America at once shows us that the countries, the physical geography and natural history of which form the subject of the following remarks, present, when regarded as a whole, an irregularly-shaped and elongated triangular outline, not unlike that of the curved upper mandible of certain birds, or one of the blades of a pair of pincers. The base of this triangle, which lies throughout a considerable portion of its width on the Rio Negro, and measures upwards of 500 miles, is close upon the 39th degree of south latitude; while the apex is not far removed from the 55th parallel. The area thus included is divided into two very unequal portions by the celebrated Strait of Magalhaens or Magellan; the *northern* section, or Patagonia, measuring upwards of 1,000 miles in extreme length, while the *southern*, consisting of an archipelago of islands of varying size, hardly exceeds a fifth of that extent.

The eastern and western sides of the region exhibit a striking contrast, not merely in respect of the aspect of their coast-lines, but also as regards their geological structure, their climate, and their natural productions. On the east of the Cordillera, or Andean chain, with its outlying spurs, there stretches a vast tract of low-lying, gently undulating, grassy country, with but few hills exceeding 400 or 500 feet in height. There is an entire absence of trees, and even plants of a

shrubby habit are not plentiful. There are but few rivers, or even streams, but salinas or shallow salt lakes abound, together with a considerable number of brackish patches of water of varying size. This scarcity of running and stagnant fresh water is to be accounted for by the dryness of the climate, the rainfall being limited at all seasons of the year. The temperature, even in the height of summer, is seldom more elevated than is the case in the month of September, or beginning of October, in the British Islands; but the clearness of the sky with the bright sunlight (in summer gilding with a deeper tint the pale yellow grass of the pampas, and in the depth of winter shining brilliantly on the snowy shroud with which the country is then covered for months at a time), communicate a feeling of exhilaration to the traveller. The geological formations of this eastern wilderness date for the most part from tertiary and post-tertiary times, the surface of the country being almost everywhere formed of a thick sheet of drift or boulder-clay, which, on reaching the coast, frequently forms, in combination with the subjacent strata, mural cliffs, which vary from twenty or thirty to four or five hundred feet in height. The coast itself presents a very uniform character, exhibiting a series of shallow bays, separated by more or less rounded headlands, with here and there a creek or small estuary where a river or stream joins the sea. It is almost destitute of fringing rocks or islands.

The narrow strip of country to the west of the Andes differs in almost every characteristic from that just described. Instead of consisting of wide grassy plains, it is of an almost uniformly elevated character, the land rising steeply from the water's edge into rugged mountainous masses of granite and mica-slate, which frequently exhibit the most wild and fantastic forms. These mountains, which often attain an elevation of from two to three thousand feet, and are sometimes as much as six or seven thousand in height, are beneath clothed with dense forests, where evergreen trees predominate, which are succeeded by ranges of grey precipices, in their turn surmounted by jagged peaks, in some instances standing out against the sky line in their savage nakedness, in others with a dazzling snowy investment. Numerous glaciers, often of great extent and splendidly crevassed, may be observed reposing in the bosom of the gorges, and here and there reaching the margin of the water, into which they discharge large fleets of miniature bergs.

The climate of this western region is of a most unenviable description, the sky being nearly at all times veiled in dense black masses of clouds, which are never weary of precipitating themselves in torrents of rain, and the land is in consequence literally drenched with moisture. Hardly anywhere is there a dry spot on which to take up a position, but everywhere the ground underfoot, and the overhanging boughs of the trees, are dripping with wet; every space of ground of any extent where trees are absent forms a bog; nearly every valley which admits of it is occupied by a chain of small deep lakes or tarns, while a perpetual sound of the trickling of rills and rushing of streams strikes on the ear. Some of the multitudinous rivulets discharge themselves in foaming silver cataracts from the bare cliffs, while others pursue their course in deep and hidden channels through the intricacies of the forest. Myriads of islands are scattered along the coast, separated by a series of tortuous channels from the mainland, which is deeply intersected with narrow and winding inlets, often many miles in length, which from their gloomy and mysterious aspect, appear, as has been remarked by Darwin, to lead beyond the confines of this world. An excessive amount of rain is not the only drawback here, for heavy showers of sleet and snow fall even in midsummer, and furious squalls (the "williwaws" of sealers) blow through the gullies in the mountains with a force which carries all before them.

The coasts of the Strait of Magellan (which serves as a connecting link between these two very different regions), partake, as might be reasonably expected, of the nature of both. This intricate passage measures from end to end about three hundred miles. In its eastern portion, except at two spots of limited extent (the first and second Narrows) where it is much contracted, it is comparatively broad, varying from ten to about thirty miles in width, and its waters are of no great depth, necessitating in many places careful sounding on the part of the navigator, in order to avoid running aground on the sandbanks, of which there are several of considerable magnitude. Its western moiety, on the other hand, seldom exceeds four to eight miles in width, and is sometimes much less, while the water, except at the debouchures of certain rivers, is nearly everywhere deep; no bottom as a rule being obtainable with a thirty fathoms line. The range of the tide in the *west* is also very slight, probably not exceed-

ing four to five feet, while towards the *eastern* entrance it is as much as from thirty-eight to forty-two feet, and its velocity in the first and second Narrows averages from five to eight knots.

At Cape Negro on the Patagonian shore, and at some distance further to the south and west on the Fuegian coast, trees are first met with, and they gradually exhibit an increase alike in number and in size on passing westward, till the grassy plains at length altogether disappear, while the land at the same time assumes a more and more elevated character.

It is in a situation in which are to a certain extent blended the features and climates of the eastern and western districts, namely at a distance of some miles to the south of Cape Negro, that some fifteen or sixteen years ago the Chilian Government established their colony of Punta Arenas, or Sandy Point, having transplanted it from Port Famine, a less favourable locality, about forty miles further south. This settlement, originally of a purely penal character, and maintained under military discipline, has grown considerably in size within the last few years, chiefly through the advent of some hundreds of emigrants from South Chilé, who have been led to shift their quarters by the inducement held out to them of free grants of land, together with the means of subsistence for a limited period, at the close of which they are expected to provide for themselves. The future of this colony may perhaps be as yet regarded as somewhat doubtful; but its condition on the whole at present is prosperous, and as coal of tolerable quality has been discovered in the neighbourhood, it may be destined in time to come to form an important port of call for steam-vessels which may prefer traversing the Strait to rounding Cape Horn.

Having stated thus much regarding the more salient points in the physical geography of the southern extremity of the American continent, we may proceed in the next place to make some observations on its fauna and flora, and we shall begin with the aboriginal representatives of the human species, of which three more or less distinct varieties tenant the region. These are, first, the Patagonians; second, the inhabitants of the Pampas district of the large eastern island of Tierra del Fuego; and thirdly, the natives of western Fuego and Patagonia, often styled "Canoe Indians."

The Patagonians, confined to the low country to the north of the Strait of Magellan, were found to be an amiably disposed and fairly intelligent people, whose principal defect appeared to consist in an overweening partiality for alcoholic refreshment, under the influence of which brawls occasionally arose among themselves, not unattended with bloodshed. Most of those encountered were of large stature, the males being rarely under five feet eleven inches in height, and not seldom exceeding six feet by two or three inches, while the tallest individual whose height was accurately ascertained, measured no less than six feet ten. The muscular development of the chest and arms is very remarkable, and doubtless fostered by their manner of life. The head usually is large, the features generally good, having commonly an aquiline cast, and the hair is long and black. Most possess well-preserved sets of teeth, with this exception that the crowns of these organs are almost invariably reduced to a uniform level; whether resulting from the nature of the diet, or produced by artificial means, was not ascertained. The skin is dark, and doubtless rendered additionally so by the absence of ablutions, which appear to be performed only at distant intervals and with very partial results. The main portion of the clothing of the men and women alike consists of an ample robe or blanket, formed of numerous skins of the guanaco, strongly and neatly sewn together with threads of sinew. This garment, which reaches from the neck nearly to the ankles, is worn with the hairy side innermost, and the outer surface is daubed with clays of various colours, which in combination with the residual grease, render it almost completely waterproof. Their principal weapon is the "bolas," a missile formed of two or three carefully rounded stones, and a corresponding number of balls of brass or iron, attached to a plaited leather thong, and specially employed in the capture of the animals which constitute the principal article of food. They also possess lazos, spears, and hunting knives, and a few are provided with revolvers, procured either from passing vessels or at Buenos Ayres, to which they occasionally resort. They are nomadic in their habits, seldom remaining long in one locality, but travelling from place to place on horseback, in the pursuit of the chase, and dwelling in temporary villages of "toldos," or tents of guanaco skins, supported on poles. They have a considerable pack

of ugly smooth-haired dogs, about the size of fox-hounds, for hunting purposes, as well as certain odd little hairless specimens of the canine race, which appear to be regarded in the light of pets, and are clothed in diminutive guanaco cloaks. The food of these people is for the most part furnished by the flesh of the guanaco and of the rhea, or American ostrich.

With the natives of the north-eastern portion of Tierra del Fuego but little intercourse took place, owing to their savage and unfriendly nature. They resemble the Patagonians in their physical stature, and to a certain extent in the nature of their food and clothing ; but they differ from them in not being provided with horses, in consequence of which they are obliged to pursue their prey on foot with the aid of their dogs. Their most important weapon appears to be the bow and arrows, both beautifully formed of a yellowish wood, which is probably that of a species of barberry, large bushes of which occur here and there on the grassy plains of the district. The arrows are tipped with neatly fashioned fragments of flint, quartz, or bottle glass.

The denizens of the western wooded region of Patagonia and Fuegia, though probably divisible into several tribes, agree sufficiently closely alike in general aspect, habit of life, and probably also language, to admit of being considered collectively. They are to be met with, at the present time, all round the coasts of the mainland and adjacent islands, as far north as the Gulf of Peñas, and formerly there can be little doubt that they also tenanted the numerous islets of the Chonos Archipelago. Alike physically and morally, they would appear to constitute one of the most degraded and miserable races of human beings. Nevertheless, no honest observer can deny that (in common with every nation under heaven), they are capable of a wonderful amount of improvement and elevation, when subjected to the ennobling influences of Christianity. The success which has attended the philanthropic efforts of the Fuegian branch of the South American mission furnishes an indubitable proof of this assertion. Generally speaking they are of low stature, and their stunted appearance is much augmented by not holding themselves upright, but being much bowed ; the result most probably of the amount of time which they occupy crouched around their camp-fires. The height of two of the men, who might be considered as average specimens, was ascertained to be

five feet three inches and five feet six inches respectively, while that of two of the women was four feet seven and four feet ten. Their skin is generally of a deep copper hue; the features are very variable, sometimes rather well cut, and at others hideous in the extreme; and the hair is black and falling in lank locks. Their clothing—when they possess any, and the contrary not seldom obtains—strikes the observer as but ill adapted to the exigencies of the rigorous climate of the region in which they live, being in general limited to a scanty cloak of seal or otter skins reaching from the shoulders about half-way down the thighs.

They spend the greater portion of their existence in journeying from place to place in their canoes in search of the shell-fish and echini which form the main article of their diet, with the addition of berries, fish, and an occasional porpoise, seal, otter, or deer. The canoes are of considerable size, constructed in some instances of five sheets of beech bark, in others of five rough planks sewn together with the leaves and stems of a kind of rush (*Rostkovia*) which they also fashion into ropes and baskets. In one of these canoes, which are propelled by means of long paddles, as many as seventeen individuals, including men, women, and children, with the addition of one or two dogs, may be observed huddled together. A smouldering fire, covered with green boughs, is always maintained in the bottom of the craft, and prevented from burning it by the interposition of a layer of clay. On reaching a spot where a good bed of mussels or *Fissurellæ* (key-hole limpets which are very plentiful in the district) occurs, the party generally disembark and construct a low bee-hive-like wigwam of branches, having their lower ends fixed in a circle in the ground, and the upper bent in and fastened together. The framework thus formed is roofed in usually with leafy branches, but occasionally with strips of bark, and a fire having been lighted, and an abundant supply of the above-mentioned molluscs collected, the family proceed to take their food. After a few days, chiefly occupied in eating and sleeping, the voyage is resumed and continued till some other suitable locality is reached.

Passing on to the lower forms of the class mammalia, we find that the species occurring in South Patagonia and Fuegia are by no means numerous. In the Pampas the principal quadrupeds are the guanaco,

which exists in vast herds, and, as already mentioned, is hunted by the Patagonians and Eastern Fuegians for the sake of its hide and flesh ; the puma or American lion, the Pampas cat, a species of skunk *(Mephitis Patagonica)*; and a considerable number of small rodents, one of the most remarkable of which *(Ctenomys Magellanicus)* tunnels the sandy soil everywhere near the sea-coast. In the wooded country there are only a few rodents, and a species of otter *(Lutra Chilensis)*. If we add to these the sea-lion and fur-seal, which are specially plentiful in the waters of the eastern portion of the Strait of Magellan, and sundry species of cetacea, the mammalian fauna may be said to be summed up.

About ninety species of birds were procured in the course of three seasons. Of these, the majority of the purely terrestrial species were met with in the open country, animal life being at a discount in the humid region of the west. The land rapacious birds were found to be represented by the condor, which breeds at one or two spots on the cliffs of the northern shore of the Strait ; a fine eagle, with a variety of other species of falconidæ ; and four species of owl, two of which, the *Bubo Magellanicus* and *Pholeoptynx cunicularius*, are remarkable for their wide distribution over the American continent, probably extending as far north as the Arctic Sea. The perching birds or Passeres were found in considerable numbers in the Pampas, some of the more characteristic being a scarlet-breasted starling *(Sturnella militaris)*, a sooty-black troopial, a thrush, a tiny wren, and several species of finch. In the woods a parroquet, two species of woodpecker, and a humming-bird, were not uncommon, and a singular aberrant form of thrush *(Pteroptochos)* was found some distance to the south of the Gulf of Peñas. Among the aquatic species, the following may be specified ;—two species of swan (one with a black neck) ; three geese, specimens of two of which often appeared at the mess-table ; about half-a-dozen kinds of ducks ; one or two gulls ; a tern ; several petrels ; a penguin, and three or four species of cormorants. Of all the above enumerated, the cormorants are probably the most plentiful, and several very remarkable breeding-places occur at various localities in the strait of Magellan, the most wonderful of all being on the small island of Sta Magdalena, where it was visited by Sir Richard Hawkins in the time of Queen Elizabeth, and nearly three hundred years later by a party from H. M. S. "Nassau."

Reptiles are very scarce in South Patagonia and Fuegia, the only representative so far as discovered being a small species of lizard, which occurs plentifully in the eastern district on both sides of the Strait of Magellan. In the humid region one or two species of amphibia (frogs and toads), were obtained. The fresh waters, whether lakes or rivers, would appear to be very poor in fish, having only yielded one or two species of the family Galaxidæ, which to a great extent replaces the trout and salmon family in the southern hemisphere. Among the marine fish may be mentioned several species of the families Trachinidæ and Atherinidæ (one of the latter being the "pecquery," which forms an excellent article of diet); a species of hake; the singular *Callorhynchus Antarcticus;* a small shark, identical with our common picked dog-fish; and a species of Myxine, a worm-like fish of low organization, allied to the lamprey.

Dismissing without notice the invertebrata, which, though including a considerable number of note-worthy species, are yet of less general interest, we conclude with a few remarks on the flora of our regions. To begin with, it may be observed, that while a certain number of species of plants are common to the eastern and western districts, the majority are almost exclusively confined to either one or the other; hence it may be advisable to treat of the vegetation of each of these tracts separately.

In the Pampas, as previously described, the plants are almost all of a herbaceous nature, there being no trees and but few shrubs. The only one of the latter, indeed, which may be said to constitute a marked feature of the plains, is a species of barberry *(Berberis dulcis)* bushes of which occur at intervals, sometimes forming dense thickets from six to twelve feet in height. Its specific appellation of *Dulcis* is well merited, as the round purplish blue berries, about the size of black currants, possess a very agreeable flavour and are much relished in consequence, alike by various kinds of birds and by human bipeds both savage and civilised. Its thick rounded masses furnish a valuable shelter in tenting out in a high wind, and its branches form a valuable ingredient of the camp fire, as they burn readily with a bright flame. Several plants of the order Compositæ, the stems of which possess a woody character, also occur, attaining a height of from one to three feet. One of these, the tallest *(Chilabothrium amelloides)*, bears

leaves much like those of rosemary, and numerous flowers with a yellow disc and white ray, a little smaller than those of an oxeye daisy. Another of somewhat inferior stature (*Lepidophyllum cupressiforme*), might readily deceive the careless observer into the belief that he had come across a dwarf species of cypress or Arbor-vitæ, so closely does it counterfeit the physiognomy of a cupressineous plant. From it as well as from a Leguminous plant of the germs *Adesmia*, frequently found associated with it, a viscid balsamic substance, with a powerfully aromatic odour, exudes in abundance.

Among the herbaceous plants of the plains may be noticed the wild celery and the singular "balsam bog" (*Azorella glebaria*), three dwarf species of *Calceolaria*, the Magellanic variety of the Birdseye primrose (*Primula farinosa*), the Thrift, the sea-side plantain (*Plantago maritima*); several species of *Acaena*, the barbed achenes of which are a torment to the pedestrian, the wide-spread Dandelion, and an orchid with a greenish-yellow flower.

In the wet wooded region the trees which are most plentiful are two species of beech (*Fagus antarcticus and F. betuloides*), the former with deciduous and the latter with evergreen leaves; Winter's bark (*Drimys Winteri*); and a sort of cypress (*Libocedrus tetragonus*), of the wood of which the Fuegians fabricate the handles of their spears, whilst the prevalent shrubs are a holly-leaved barberry (*Berberis ilicifolia*), with splendid orange blossoms; the curious *Desfontainea spinosa*; a kind of heath (*Pernettya mucronata*); a species of *Fuchsia*; an *Escallonia*; and the evergreen *Veronica decussata*. A very beautiful under-shrub (*Philesia Buxifolia*) abounds beneath the shade of the trees, and the herbaceous plants include two handsome species of orchids, and a variety of bog plants, such as the curious *Astelia*, a little Sundew, an *Oxalis*, and two remarkable species of *Caltha*. Cryptogamia abound in this region, being represented by ferns of the genera *Gleichenia*, *Asplenium*, *Lomaria*, *Cystopteris*, *Hymenophyllum*; a few *Lycopodiums*; many species of mosses and liverworts; some magnificent lichens, and a considerable number of fungi.

The marine Algæ appear to be more numerous in species in the waters bounding the eastern region than those of the west. The most plentiful and characteristic of all is the well-known "kelp" *Macrocystis*

pyrifera, which forms a girdle around the coast, and attains gigantic dimensions in respect of length ; single plants not seldom measuring several hundred feet.

29th January, 1873.

A Paper was read by JOSEPH JOHN MURPHY, Esq., F.G.S., President of the Society,

On the Solar Spots.

Mr. Murphy began by referring to his opening address to the Society on 21st November, 1872, in which he spoke of the darkness of the Solar Spots as altogether unexplained. In the conversation which followed, Professor Everett made a suggestion as to its cause, on which Mr. Murphy has based the present communication.

It is a visual fact that the spots are funnel-shaped depressions in a stratum of luminous clouds, and it is in the highest degree probable that these depressions are due to vortexes in the atmosphere of the Sun, analogous to the cyclones or revolving storms in that of the Earth; for it is a familiar fact, illustrated in every stream of water, that the centrifugal force of a vortex produces a depression at its centre. The distribution of spots on the Sun is analogous to that of cyclones on the Earth: that is to say, they do not occur either on the equator or near the poles, but always in zones on each side of the equator. The probable reason for this distribution of terrestrial cyclones is, that they originate in the conflict of the north and south trade-winds, when they meet at some distance north or south of the equator.

The reason of this distribution of cyclones on the Earth's surface appears to be well understood. The heating of the equatorial regions causes an indraft of air at the Earth's surface, towards the equator, for the same reason that there is an indraft close to the floor of a room, towards the fire. These indrafts are formed on both sides of the equator; they are deflected by the rotation of the earth, and con-

stitute the trade-winds. We have not now, however, to do with this deflection; we have only to do with the fact that they meet along the hottest zone of the earth. The line along which they meet follows the apparent motion of the sun, so that at the equinoxes it approximately coincides with the equator, but falls several degrees to the north in the summer of the northern hemisphere, and several degrees to the south in the summer of the southern hemisphere.* When currents, whether of water or of air, meet, eddies or vortexes are frequently formed, and the vortexes which are formed at the meeting of these currents are, under favourable circumstances, developed into cyclones. This, however, cannot take place on the equator; it takes place only when the meeting of the currents is some degrees to the north or south. The reason of this is as follows:—If a spectator in planetary space were to look down on the Earth at the north pole, he would see the Earth rotating in a direction opposite to that of the hands of a watch; were he to look down on the south pole, he would see the Earth rotating in the same direction as the hands of a watch; and were he to look down on the equator, he would see the earth rotating in neither direction, though still rotating. This is geometrically expressed by saying, that if an axis is drawn vertical to the horizon, the Earth's surface, at the north pole, rotates round such an axis in a direction opposite to that of the hands of a watch, and at the south pole, in the same direction as that of the hands of a watch, while at the equator it does not rotate round such an axis at all. In moving from the equator to either pole, the motion of the Earth's surface, in relation to such an axis, increases with the sine of the latitude.

Suppose an eddy to be formed at some distance from the equator, in either hemisphere, with a rotation in the same direction as the earth's surface in that hemisphere, the following actions will take place:—The centrifugal force of the eddy will throw out a quantity of air from its centre to its circumference, thus diminishing the quantity of air at the centre, and with it the barometric pressure. At the same time, the friction of the moving air against the Earth's surface will diminish the force of its motion at the surface, and therefore also the centrifugal force, while it remains undiminished at greater heights. There will be a flow of air towards the centre of the eddy as being the place

* See Mr. Murphy's letter on the "Origin of Cyclones" in *Nature* of 17th August, 1871.

of lowest barometer, and this will take place at the surface of the Earth as being the place of least resistance from centrifugal force. Meantime the Earth is rotating under the eddy, and as we are supposing in the same direction, and each of the threads of air that seeks the centre of the eddy will, in virtue of the law of inertia, tend to move in an absolutely straight line, which does not move with the rotation of the earth, but remains fixed in space. The effect of this will be that these threads of air will be deflected in the northern hemisphere to the right, and in the southern hemisphere to the left, of the centre of the eddy: and this deflection, being by supposition in the same direction with the rotation of the eddy, will increase its force, and will tend to develop it into a cyclone.

This deflection of the centripetal currents of air is precisely similar to the deflection of the trade-winds from their north and south course. It may, however, be better illustrated by the fact, that a cannon ball, shot in the northern hemisphere, falls a little to the right of its mark, and in the southern hemisphere, a little to the left. It is not that the ball really moves in anything but a straight line: it is that the earth is moving under the track of the ball, which has consequently an apparent motion in the opposite direction. This will be seen in the following diagram, where the straight arrows will serve equally well to indicate the paths of cannon balls, or of the currents of air towards the centre of a cyclone. For the sake of simplicity, let us suppose the letters N and S to represent, respectively, the north and south poles, though, in point of fact, cyclones are not formed in the polar regions. The bent arrows indicate the direction of the Earth's rotation round a vertical axis.

A glance at the diagram will show how the vortex, if originally set in motion in the direction of the Earth's rotation, as shown by the bent arrow, will have its rotatory tendency increased by the deflection of the inflowing currents of air, as shown by the straight arrows. Of course it is not meant that the paths of the currents are really straight—they are in fact spiral.

The above is not offered as a complete theory of cyclones, for it takes no account of the way in which their force is increased by the liberation of heat from the condensation of vapour. It is only offered as an account of the way in which the cyclones of the Earth's atmosphere begin, and it appears to be applicable, without the change of a single word, to those of the Sun's atmosphere.

The sun, as Secchi has ascertained, is hotter at the equator than at the poles. This may be due to a greater number of meteors falling in at the equator, for though the "meteoric theory of solar heat" is disproved as a complete theory of the subject, it is not improbable that a sensible proportion of the sun's heat is produced by the falling in of meteors.* But whatever may be its cause, the effect of the excess of heat at the equatorial region of the sun must be to produce an atmospheric circulation like the trade-winds of the earth; and in the violent agitations of the sun's atmosphere, increased sometimes perhaps by meteoric showers, it is probable that the meeting of the north and south trade-winds will sometimes occur far enough from the equator to produce cyclones.

We have next to account for the darkness of the spots. The old theory that they are due to a dark body of the sun appearing through a rent in the luminous clouds is now seen to be untenable, for the sun's body could not be darker than the clouds unless it were also colder, and no body can remain permanently colder than its envelope. The darkness of the spots must be due to local and temporary cooling, and the only source of cold that can be suggested is a downrush of cold air from the upper strata of the atmosphere. When a cyclone is formed in the lower strata, and a partial vacuum formed at its centre by its centrifugal force, analogous to the depression at the centre of a vortex of water, the air of the cold upper strata will

* See the President's opening Address in this Volume.

rush down into the vacuum so as to cool and darken the luminous clouds. This view is supported by the distribution of the "pores," or minute dark spots, which do not appear to be cyclonic, though the larger spots originate in them. They are found in the hollows of the waves into which the luminous clouds of the sun's atmosphere are tossed, and consequently where there are most likely to be descending currents of air from the upper strata to cool the clouds.

It is certain that in the sun's atmosphere a downrush of air must have a cooling effect. The temperature of an atmosphere is said to be in a state of convective equilibrium, when the difference of temperatures at any two heights corresponds to the difference of barometric pressures; so that a mass of air, if carried from one stratum to another, will ot once assume the temperature of the stratum to which it is carried. When the temperature of the earth's atmosphere diminishes at the rate of about one degree Fahrenheit for every 180 feet of ascent it is in a state of convective equilibrium. In such a state of things a downrush would have neither heating nor cooling effect; and, were the diminution of temperature in ascending less than this, a downrush would have a heating effect. But in these two cases there would be nothing to cause a downrush. If, on the contrary, the diminution of temperature on ascending is greater than is due to a convective equilibrium, a downrush will bring cold. The violent vertical circulation which is seen to be constantly going on in the sun's atmosphere shows that such is the state of things there. The upper strata are cooled by radiation into space; in cooling they contract, and as the contraction increases their specific gravity, they sink down, cooling and therefore darkening the clouds below, while columns of hotter air arise from below to take their place. This circulation is precisely similar to that which takes place in boiling water.

29th January, 1873.

Joseph John Murphy, Esq., the President of the Society, in the Chair.

A Paper was read by ROBERT YOUNG, Esq., C.E.,

Some Remarks on Fossil Teeth and Bones lately discovered in Phosphatic Manure from America.

My attention was first called to these very remarkable objects at the late show of the Royal Irish Agricultural Society, held at the Ormeau Park, where Mr. Scott, a manure merchant of this town, exhibited a quantity, to show the genuine material from which bone dust and phosphates are manufactured.

Being much struck with the gigantic proportions of some of the teeth and bones, which far exceeded any in our local or other museums I had visited, I was anxious to ascertain the exact locality and stratum from which they were derived. On making enquiry I found that several cargoes of these bones and teeth had been brought here within the last few years from Charlestown, South Carolina, that they were dug out of the swampy ground at various places near that town, and that these and the rotten rock and soil with which they were associated were all ground up together, and, after being treated with acids, formed the phosphate manure so much in request for land.

A relative who happened to be on a visit with me, and who was about to return to New York, was equally interested with myself, and promised to make enquiries in the proper quarters, and if he found there was any hope of the entire skeleton of one of these gigantic creatures being found in situ that he would go down and supetintend its careful exhumation.

I saw this gentleman about two months after this in Belfast again, when he informed me that he had written to Professor Hitchcock on the subject, and got the following information :—that the beds in which these fossils were got at Charlestown were recent drifts, that all the bones and teeth were much waterworn, and there was, therefore, no possibility of getting any two in their original connexion ; that Professor Holmes, of Charlestown, was the first authority on the subject, as he had examined the whole district, and had made a very large and valuable collection of these remains. A paper by Dr. Holmes on the subject of the Charlestown phosphates, and the recent work of Dr. James Dana on American Geology, have enabled me to offer some observations on the discovery of these fossil beds, and their geological age and position. What are on the table are fair specimens of these remains. The teeth are those of a gigantic shark, the *Charcaradon*, so called from the serrations on its edges, and of another and smaller species, *otodus appendelatus*, having a smooth edge. Some of the former are about four inches high by three inches wide at base. I have to thank Dr. Henry Burden for assisting me in determining these species. With regard to the large vertebræ he is not so clear. They might possibly belong to some terrestrial mammal of mammoth bulk, but it seems more likely they are the remains of whales, as they are known to have been very numerous in the earlier tertiary seas.

The special localities where these are being dug up, as I find stated in a report of 1868, at the rate of several thousand tons per annum, are all upon rivers which are in the vicinity of Charlestown, viz.:—Ashley, Cooper, Stano, Edisto, Bull River, Combahie, but they are developed to the largest extent along the Ashley, and, in fact, form the surface rock for many square miles in that district, only covered slightly by vegetable soil.

It seems about twenty years ago this district was examined by Professor Agassiz, principally with reference to its fossil marine vertebrata, and he pronounced it the greatest *cemetery* he had ever seen.

Professor F. S. Holmes seems to have been the next scientific man who made it a subject of investigation, and in 1850 he gave a very valuable paper upon it and the associated tertiary beds. However, it was not until 1867 that the practical value of these beds as manures was attempted to be developed. A Mr. Pratt, who had

been employed by the Confederate Government as a practical chemist, and who was acquainted with the district through the saltpetre beds on the Ashley River, when the war was ended turned his attention to the utilizing of the phosphates in the fish-beds on that river, as had been suggested to him by Professor Holmes. He found the nodules, or conglomerates, from the beds to contain about 56 per cent. of phosphate of lime, and, on making an extended enquiry to determine the area, he found they had an enormous extension inland, and he resolved to establish works for the manufacture of fertilizers, which it seems were greatly wanted to restore the exhausted lands in that State. In obtaining capitalists to assist him in this large enterprize, he was greatly assisted by a curious coincidence. A work on geology, published by Professor Ansted some years before, but which, owing to the war, had not reached this part of America, had just then been received in Charlestown, and in it he described most valuable beds of phosphate rock as having been lately discovered in exactly an analagous position in tertiary beds of the London Basin. The result was immediate attention being given to the matter, and the formation of a company called "The Charlestown South Carolina Mining and Manufacturing Company," of which Professor Holmes was president, and Mr. Pratt chemist and general superintendent.

The geological position of the bed from which these phosphates are obtained will be best understood by beginning with the underlying cretaceous rocks as shown in the section now before the meeting.

Above there are the tertiaries—the Eocenes which in this locality are known as the Ashley marl beds, and are about twenty feet thick, as found by an artesian well sunk at Charlestown. They are composed almost entirely of microscopic shells, and infusorial cases of shells of a group called Polythalamia, resembling ammonites and nautili. There are also some few oysters and hard shells found, and some corals. These marls are full of the teeth and other remains of sharks and whales, but no remains of any land animals have yet been found in them. The Miocene formations are wanting in this locality, and the next beds above are the Pliocene, which occur in the form of sand, clay, gravel, and marl strata, but chiefly the first: seldom thick or continuous, but in detached patches.

In basins on the surface of these Pliocenes are found the thin

beds of the phosphatic rocks. These consist mostly of nodules or lumps of the Eocene marl rounded and waterworn. These seem to have been formed when the country had been raised only to a small height from its position at the end of the cretaceous period, so that the nodular fragments were rolled about by the waves, and at length driven in and lodged in the shallow lagoons enclosed by the outlying sand-banks, which had their origin probably much in the same way that the lagoons are being still formed by the well-known *keys* along the same coasts at the present day.

Let us now imagine the lifting up of the whole Eastern coast-line and sea bed along with it, to the extent of about 10 feet vertically. We would then have a number of small salt lagoons formed along the coast, having their bottoms paved with the fragments or nodules of the Eocene beds. The well-known phenomena of the formation of salt-rock would be commenced by the alternate evaporation of water and deposit of a layer of salt. At length these places would get partially wooded, and become the resort of the huge mammalia of the Postpliocene, corresponding with the preglacial period, when the mammoth, mastodon, megatherium, rhinoceros, and American elephant roamed through the uplands and repaired to the salt licks, and often, doubtless, left their bodies in these lagoons, unable to extricate themselves from the tenacious mud into which they had ventured. In this way only can it be understood how the bones of these more recent mammals are found mingled with those of far older marine animals; and it also helps to explain the extraordinary richness of the nodules and other parts of the bed by the theory that they have been saturated, so to speak, by the phosphates resulting from the dead bodies and fœcal remains of these huge mammals who were thus entombed above them.

5th February, 1873.

William H. Patterson, Esq., in the Chair.

A Paper was read by Dr. ROBERT STEEN,

On Notes of a Tour through Norway.

This paper consisted mainly of a record of incidents of travel. The route followed was that leading from Christiania over the Fille Fjeld to Laerdalsoren, on the Sogne Fjord, and thence by steamer up the picturesque Næro Fjord to Gudvangen. From Gudvangen to the immense Hardanger Fjord the journey was made by land. The homeward tour was through the wild region called Tellemarken, some parts of which are as yet unprovided with roads.

Passing over part of the narrative of adventure and travel, and condensing the other portions of the paper, some points which may prove interesting to the reader may here be noted.

The first glimpse which the stranger gets of the Norwegian coast shows it to be very different from what he is accustomed to see at home. Instead of a sandy beach, he sees smooth rocks shelving down to the water's edge. In some cases these rocks are partially covered with a stunted vegetation. The water near the land is generally of a depth sufficient to float large vessels.

Christiansand is the first town which the tourist who sails from Granton or Hull is permitted to behold. It presents, as seen from the deck of a steamer lying in the bay, a very charming appearance. Although Christiansand appears to the traveller from England only a village, it ranks as the fourth city in Norway. Christiania, the capital, possesses but little interest for the tourist in search of the beautiful. It is a town of 60,000 inhabitants, and contains only a

few buildings of any note. The chief of these are the Palace, the University, and the Houses of Parliament. The Storthing assembles once in three years, and sits only for three months. The whole Storthing, when elected, chooses from its own body the one-fourth, which constitutes the Lag-Thing, or Upper House. The other three-fourths form the Odels-Thing, or House of Commons. The Norwegian Parliament possesses a right not enjoyed under any other European Monarchy. When a Bill has passed through three successive Storthings it becomes on the third occasion the law of the land, even although the King may have refused to give his sanction to the measure.

It is only when we leave Christiania and penetrate into the country that we realise that we are in a foreign land. The villas of the wealthy citizens are charmingly situated, commanding beautiful views of the Christiania Fjord.

One of the earliest impressions produced on the traveller is that caused by the magnificent roads recently constructed by the Norwegian Government. The old roads are extremely hilly; those, however, which have lately been made are triumphs of engineering skill. In some cases they have been blasted out of the solid rock, in others they have been built of solid masonry over fearful precipices, and everywhere they are free from sharp ascents or descents. Along the wayside snow-ploughs are often to be seen, which are used during the cold season for keeping the roads open for traffic. Although the roads are made by Government, each farmer living in the district through which they pass is bound to keep a certain portion of them in good repair. Along the roads wooden posts are observable, surmounted by a triangular piece of wood, underneath which figures may be seen recording the number of yards or perches which fall to the share of the particular farmer charged with the maintenance of part of the road.

Norway possesses but few railways. Stockholm, the capital of Sweden, is connected with Christiania by rail. A very excellent narrow-gauge railway runs from the capital to Drammen, a flourishing town on an arm of the Christiania Fjord, and thence to Kongsberg, where for centuries silver mines have been in operation. The Norwegian Government has resolved to construct a railway from Chris-

tiania to Trondjem. Part of this line is already finished as far as Eidsvold, on the Mjosen Lake, and another small piece of it has been completed in the neighbourhood of Trondjem.

Waterfalls form the chief characteristic of Norwegian scenery, and these are of great beauty and variety. As the mountains of Norway form immense table-lands, terminating abruptly in precipices, the waterfalls are usually of great height, and are unprovided with that background of foliage which in other countries form their peculiar charm. The Norwegian cataract falls usually in a single leap, and is different, therefore, from that of Switzerland, which often forms a succession of cascades. Forbes remarked that some of the Norwegian waterfalls, which seem in the distance like silver threads, when approached turn out to be raging torrents of considerable volume. The four largest waterfalls of Norway are the Ruikan Foss, in the Thelemarken; the Voring Foss and the Skjeddedals Foss, on the Hardanger Fjord; and a fourth called by Mr. Campbell, in his book "How to See Norway," the Mörk Foss.

The tourist is surprised at beholding, not far from the Sogne Fjord at Borgund, an old church of a very peculiar style of architecture. This church and a similar one at Hitterdal, both of which we saw, are the two most ancient architectural structures in the whole country. Both of them are being very carefully preserved, as indeed they deserve to be, for they are quite unique in shape, colour, and internal arrangement. The traveller beholding the Borgund Church, which rises gable above gable, narrowing as it ascends, is reminded of the descriptions given of a Chinese pagoda. Professor Dahl, who has made a study of these ancient architectural remains, thinks that they have a close connection with the Byzantine style.

The route taken by the majority of tourists in Norway is to proceed by rail from Christiania as far as Eidsvold, then to cross by steamer the Mjosen Lake, which is the largest in Norway, and then to proceed onwards through the Gudbrandsdal and over the Dovre Fjeld to Trondjem. The scenery of this route has been greatly overrated. The Mjosen Lake is not surrounded by lofty mountains, nor does it afford much interesting scenery of any kind. Well-cultivated fields form the chief feature of this district. The inhabitant of Norway, who is wearied with gazing on bare and savage precipices,

on which nothing save pines can exist, is delighted to feast his eyes on fertile fields and waving corn. The tourist, however, who comes from the plains of Northern Germany, or from the well-tilled fields of England or Scotland, prefers to behold the rugged mountains and noble cataracts with which this country abounds.

Everyone visiting Norway cannot fail to be impressed by the smallness of the population. It is scarcely credible that a country extending from the Naze to the North Cape, a distance of more than 1,000 miles, and varying from 250 to 50 miles in breadth, should contain a population less than the half of that of London. The fact, however, that the vast mass of the country consists of rock and mountains, plateaus which produce nothing but coarse grass and pines, shows that the population is quite as large as we have any right to anticipate. A writer in *Blackwood's Magazine* makes the paradoxical assertion that Norway is the most thickly-peopled country in Europe, and he defends this proposition by showing that wherever the people are they throng, and that, indeed, they abound wherever they can find standing-room. The writer in *Blackwood* might have strengthened his position by referring to the extensive emigration which has been going on for years. In Spring the steamers plying between Norway and Britain are crowded by these white-haired Scandinavians on their way to America by way of Liverpool or Glasgow. The States frequented by Norse emigrants are Wisconsin and Minnesota. The existence of emigration at all seems to afford a proof that the country is over-populated, for here, at least, the people do not complain of their Government or Constitution.

The mode of travelling customary in Norway is a necessary consequence of the smallness of the population. The towns are very few in number; even a village is seldom to be seen. On the Fjords and inland lakes there are excellent Government steamers, which supply a rapid means of locomotion. The roads are portioned out into distances or stages varying from about seven to thirteen English miles. A stage is called "skyds," pronounced "schuss." At the end of each stage there is a farm-house, which also serves the purpose of a rude inn. The farmer is obliged by Government to keep a certain number of horses for the accommodation of travellers. The stations are of two kinds—fast and slow. At the fast stations

horses are supposed to be always ready for the use of tourists, whereas at the slow stations the farmers of the district are bound to furnish horses. In the books of travel written on Norway the authors continually complain of annoying detention at these stations. I feel bound to state that our party did not experience this discomfort: we nearly always found the horses ready to start at a few minutes' notice.

Those who wish to travel very expeditiously are in the habit of sending forward *forbud*, as it is called. *Forbud* means a message sent a few hours in advance desiring the *Skydsskaffer*, or Postmaster, to have a certain number of horses ready at a given time. At some of the stations good food and comfortable accommodation can be procured; at others the entertainment is of the simplest description. At one place we could obtain nothing except a little coffee and the universal *fladbrod* of the country; in another, as a great treat, they furnished us with a few eggs. These were duly boiled and placed on the table, but it was then discovered that there was only one teaspoon in the house. Under these circumstances, we asked the hostess to boil the eggs hard, and partook of them in a primitive manner.

The chief vehicle of Norway is the *carriole*, which holds only one traveller besides the little boy who accompanies the tourist from one station to the other in order to drive the horses back. The second kind of conveyance is the *stolskjaerre*, which is much less comfortable than the *carriole*. As it holds two grown-up persons besides the post-boy, it is preferred by many to the *carriole*. All tourists in Norway are delighted with the horses, which are extremely sure-footed and easily managed. They are nearly all alike in appearance, being cream-coloured, with a dark line running down the back.

The people of Norway are strong and healthy. Their food is very simple, and consists mainly of *grod*, or porridge made of rye meal, and the bread which is to be seen everywhere—viz., the *fladbrod*. This bread somewhat resembles the Scottish oaten cake, except that it is much thinner and not so palatable. Of course, fish is abundant in the neighbourhood of the Fjords, which penetrate in some cases 150 miles into the interior. There does not seem to be much poverty in Norway, and there are no workhouses for the poor. Those who require support are told off to the different farms to be supported by the owners of the soil.

The finest scenery which we were privileged to behold was that offered by the Næro Fjord, which is a branch of the immense Sogne Fjord. In consequence of the height of the surrounding mountains, sunshine seldom reaches the surface of the water. The scenery becomes more impressive the nearer the steamer approaches the head of the Fjord at Gudvangen, until at last the Keel Foss, a fall of not less than 1,000 feet, appears in sight. The scenery of the valley leading from Gudvangen to Vosseoangen scarcely yields in grandeur to that of the Næro Fjord. Barren mountains rising to the height of from 3,000 to 4,000 feet form the sides of the valley, and these approach each other so closely that but little room is left for the road. Lest I should seem to exaggerate the sublimity of the scenery of this part of Norway, I shall quote a few lines from Bayard Taylor, the eminent traveller. He writes:—"The stream of the most exquisite translucent azure-green rolled beside us, and the mountain crests towered so far above us that our necks ached as we looked upwards. I have seen but one valley which in depth and sublimity can equal the Nærodal—the Pass of the Taurus, in Asia Minor, leading from Cappadocia into Cilicia."

On the day on which we left Gudvangen we reached Eide, on the Great Hardanger Fjord. We performed the last stage on foot during the coolness of the evening. It was eleven o'clock before we arrived at Eide, where we found the chief inn quite full. The second inn of the place was enveloped in complete darkness. Finding that we were unable, by dint of knocking, to awake the inmates, we turned the handle of the door, and, entering the house, we proceeded, after finding candles, to search for beds. Up stairs the rooms seemed all occupied, and the sleepers turned uneasily as the light of the candle fell upon them. On the ground floor we discovered two rude beds, on which we threw ourselves, and soon fell into a refreshing sleep. Next morning, as we left early to catch a steamer sailing from Eide, we were up betimes. Still, however, no one in the house was stirring. We accordingly placed some money on the table, and came away astonished at the honesty and simplicity of the Norwegians, who seem never to lock their doors at night.

Whilst sailing from Eide to Odde, we had a fine view of the Folgefond Glacier, which extends about forty miles along this arm of

the Hardanger Fjord. We spent a day in exploring the Buer Brae, a part of this immense glacier, and found it quite as interesting as the celebrated glaciers of Chamounix, or the Bernese Oberland.

On leaving the immense Hardanger Fjord, we struck into the Tellemarken, a district of great sublimity, combined with wildness. Until the new roads are completed, we could not recommend tourists to follow our route. At first we had an excellent new road, which continued for some miles. This, however, came to an abrupt termination, and we had to trudge on foot, under a broiling sun, and with our knapsacks on our backs, to the next station, where we procured two horses. One of these was provided with a saddle, but the other had only a rough pack-saddle, with stirrups made of ropes, and a bag of hay, on which the tourist was required to balance himself. This operation was tolerably easy on a rough bridle-path; but when a river or lake required to be forded, which often happened, it was an extremely uncomfortable sensation to be perched on a horse's back, swinging to and fro on a bag of hay, and expecting every moment to be precipitated into the water. Our course that evening was an ascent of the Hardanger mountains. Gradually we got out of the region of vegetation, until we reached a wild district of stones and torrents. The journey was enjoyable as long as daylight lasted; but about eleven o'clock we were enveloped in total darkness. Our guide conducted us through morasses and ground covered with huge stones, until at last we began to think that he had lost his way. It was now after midnight, and still we had not arrived at our destination. My strength was almost exhausted, and I proposed that we should lie down and wait for the dawn. This proposition, however, was not accepted by the rest of the party, and we accordingly pushed forward, until at one o'clock we arrived at a hut or *sæter* as it is called. All the inmates had retired to rest, and the two or three beds which the house possessed were occupied by travellers who had preceded us. The people of the house spread a few coarse rugs on the hay-loft, and we lay down on the hay in company with the owners of the place, where, on account of the cold, we slept very indifferently.

Next day we made our way through this district of the

Tellemarken until we reached high-roads once more. This region is extremely wild, and the stations are wretched and very dirty.

In passing over the plateau of the Hardanger we saw a little animal which we had never before seen, viz., the lemming. This creature is not unlike the guinea-pig, being of an orange tawny colour, with black bands and spots, and a tail about half an inch long. Its entire length is about six inches. The home of the lemming is Lapland, which, becoming overstocked with them, sends forth every five or six years vast swarms. They are said to march in parallel lines, about three feet apart, until they reach the sea, into which they enter and perish. They have been compared to locusts on account of their destructiveness and their immense number.

In travelling through the Tellemarken we were impressed by the solitude of the region, and by the immense pine forests which seem to extend for hundreds of miles on all sides. On our return to the capital we passed through Drammen, a flourishing little town which does a large timber trade. At this place we found a small steamer which conveyed us to Christiania just in time to catch the steamer for Granton.

5th March, 1873.

JOSEPH JOHN MURPHY, Esq., F.G.S., President of the Society, in the Chair.

A Paper was read by Dr. HENRY BURDEN,

ON FOSSIL TEETH.

IN the course of his inquiries into the nature of the extinct Fauna of our planet, the Palæontologist is often induced to hazard a conjecture as to the entire organization of an animal from the examination of mere fragments of its body. These fragments are usually such hard and insoluble parts as can alone, under ordinary circumstances, resist the long continued action of destructive physical and chemical agencies. Teeth are eminently endowed with the properties referred to, and they are, consequently, in many instances the sole relics of animals whose other organs have succumbed to the various disintegrating forces that have been brought to bear upon them.

In such cases it not unfrequently happens that from the shape and microscopic appearance of a tooth, or even a portion of one, the skilled anatomist considers himself justified in inferring a multitude of details concerning the size, form, structure, food, and habits of its original possessor, and in deducing from these premises much relating to the former climate and physical geography of the region in which the fossil has been found.

The question here naturally suggests itself—On what basis does a belief in the validity of such inferences and deductions rest? A so-called law of definite and constant Correlation of Structures, advocated and exemplified with remarkable ability by its chief ex-

pounder, the great comparative anatomist Cuvier, has heretofore constituted our only trustworthy foundation. This law may be stated in the following terms :—Certain modifications of animal structure are observed to be invariably accompanied by one or several anatomical peculiarities, apparently in some way necessarily connected with them, and on that account similar combinations, it is inferred, have probably subsisted in the past, and will do so in the future. But while inferences, arrived at by the aid of the principle in question, have in not a few notable cases been amply confirmed by subsequent discovery, we must ever bear in mind that, though founded on a vast array of instances, the so-called law amounts to no more than a reasonable belief, until we can show that the correlated structures stand to one another, or to some third circumstance, in the relation of cause and effect. Bacon contemptuously remarks, with reference to inductions like those under discussion :—

"Inductio quae procedit per enumerationem simplicem, res puerilis est, et periculo exponitur ab instantia contradictoria, et plerumque secundum pauciora quam par est et ex his tantummodo quae presto sunt, pronunciat."

The wonderful ingenuity with which Cuvier, Owen, and Huxley have attempted the ideal reconstruction of extinct animals from the data furnished by one or a few more or less perfect fossil remains of their teeth or bones justly excites our admiration ; but anyone who has attentively studied the works of the authorities cited, must have remarked that they are themselves well aware of the indecisive nature of the evidence. One cannot then but await with eager expectation the verification of some such law of causation as that which Darwin has so laboriously and judicially sought to establish. In the meantime the careful examination of instances, and the cautious use of what guiding principles we possess, cannot fail to clear the way for the application of genuine laws whenever they shall have been discovered.

The preceding remarks appear to me not uncalled for, knowing, as I do, what unlimited powers of divination are ascribed by the uninitiated to comparative anatomists. I shall now endeavour to show that, even when divested of the fictitious charms with which it has been clothed, the study of fossil teeth is one fraught with much interest.

It is my intention in the first place to sketch the relations of teeth to other parts, their shape, minute structure, and development; then to treat briefly of the characters which distinguish the teeth of different classes of Vertebrata; and, lastly, by the special description of a few examples, to indicate the real significance of the evidence as to correlative structure obtained from this source.

True teeth are met with in Vertebrata alone, and are limited in situation to the cavity of the mouth and throat, except in the case of a snake called Rachiodon, in which the inferior spinous processes (hypapophyses) of several vertebræ project into the gullet, are coated with dental tissue, and perform the office of teeth. If the series of dense tooth-like appendages which garnish the edges of the rostrum in Saw-fishes (Pristis) be regarded as true teeth, they also must be included with those of Rachiodon as exceptions, for they are undoubtedly outside the cavity of the mouth.

Teeth are developed from the deep vascular layer of the mucous membrane lining the mouth. This layer corresponds to, and is continuous, at the margin of the lips, with the vascular part of the integument called the Cutis vera or Dermis. It has been found convenient on this and other accounts to use the term Enderon to signify both of these structures. Teeth are, therefore, sometimes described under the head of enderonic appendages.

In the higher Vertebrates these organs are connected with the upper and lower jaw bones only; but in lower groups of the sub-kingdom they may be related to almost every one of the bones which bound the oral and pharyngeal cavities. In a typically complete tooth it is possible to distinguish a free part, called the *Crown*, which projects beyond the gum, a basal portion, called the *Fang* or *Fangs*, which is usually inserted when distinct into a simple or divided bony socket, and a more or less constricted region, called the *Neck* or *Cervix*, connecting these divisions.

A tooth in most cases encloses a soft, vascular, and sensitive substance called the *Pulp*. When this dries and shrinks after death, a cavity is left which, at the base of the tooth, communicates, sometimes by a widely open aperture, sometimes by one or several contracted canals, with the exterior.

Four different kinds of dental tissue have been defined, namely,

Dentine, Enamel, Cement, and Osteodentine. Dentine forms the principal bulk of most teeth. Though exceedingly dense, it is permeated by a closely approximated, usually parallel, series of tubes which open by one extremity into the pulp cavity or its extensions, and pass from thence into the substance of the tooth.

These Dental Tubuli, as they have been called, gradually diminish in size towards their terminations, and give off lateral branches in their course. They are commonly bent into a succession of undulations. The diameter of the Tubuli of human teeth at their proximal and larger ends is about the $\frac{1}{4500}$th of an inch. In the living tooth they contain soft fibres which are continuous with the pulp, but are not accompanied by any of its blood vessels.

Chemically, Dentine consists of about 30 or 40 per cent. of an organic substance yielding gelatine, and of mineral matter, the chief constituent of which is Calcium Phosphate. Enamel is applied, as a closely fitting investment, to that surface of the Dentine which is furthest from the pulp. It possesses extraordinary hardness, and is, in its typical form, composed of parallel, prismatic, usually six sided fibres, the long axes of which are perpendicular to its bounding surfaces. These fibres are in most Mammals marked by numerous fine transverse striae. In man their average diameter is the $\frac{1}{5000}$th of an inch. Cement always lies outside the dental tissues already described, and is in contact with one or both of them, according to the absence, presence, or extent of the Enamel. It differs in no essential particular from bone, either in chemical composition or in structure; being, however, commonly devoid of blood vessels, Haversian canals are, as a rule, not developed in it. The chief exceptions to the rule are met with in the Ungulata and Edentata, where the teeth are coated with a thick vascular layer of Cement. Osteodentine appears in fully grown teeth in the form of a deposit upon that surface of the Dentine which constitutes the boundary of the pulp cavity. As its name implies, it is a substance possessing structural characters intermediate between those of Bone and Dentine. Several modifications of the above described tissues occur in particular species or groups of Vertebrata.

The first stage in the development of a tooth consists in the outgrowth of a more or less conical process of the mucous membrane termed a Papilla. Upon this, as upon a mould, a cap of dentine is

produced by the conversion of its tissue into the latter substance. A portion of the Papilla usually remains, in the interior of the fully formed tooth, unconverted into Dentine, and constitutes its pulp.

The teeth of some animals (Sharks), never pass beyond this stage; but in others, to this simple form of development may be superadded one or all of the following complications. Thus the Papilla may become situated at the bottom of a pit or groove in the mucous membrane; ridges of the membrane may extend across the groove and form partitions between the Papillæ, each of the latter being in this case surrounded by a separate follicle; the margins of the follicles may grow together, and enclose the Papillæ in shut sacs, which are necessarily ruptured by the teeth before they can be brought into use; lastly, the sacs may come to be imbedded in closed cavities of the subjacent bone, previously to their eruption.

In the majority of cases when the tooth acquires its permanent form further growth ceases, and the opening into the pulp cavity becomes very much reduced in size. On the other hand, the tooth may, as in the incisors of all, and molars of some, Rodentia, in the tusks of Elephants, and the molars of many Edentata, continue to receive fresh additions to its substance throughout the animal's entire life, and, under these circumstances, the pulp cavity presents a large orifice. In some animals one set of teeth only is produced, in others two or more successive sets are developed.

Let us now proceed to consider the general characteristics in the several dentigerous Vertebrate classes.

MAMMALIA.

The only character which can be said to be peculiar to Mammals is the division of the root of certain teeth into two or more fangs, each of which is implanted in a distinct bony socket.

In this class the teeth are connected with no other bones than those forming the margins of the jaws, viz., the Maxillæ, the Premaxillæ, and the Mandible.

The fang or fangs are, with rare exceptions, as in Physeter, inserted into closely fitting osseous cavities of corresponding size and shape; but only in abnormal cases do they become anchylosed to the bones which support them.

The boundaries of the regions named Crown, Fang, and Cervix

are, in consequence, very evident. From considerations derived partly from their form, in some measure from their position, but primarily from their use, anatomists recognise three kinds of teeth, viz., Incisors, Canines, and Molars. The teeth of Mammals exhibit for the most part a simple pulp cavity, which may, however, be produced into lamellar extensions, embraced by the folds of dentine characteristic of certain groups, or be continuous with tubular off-shoots (*medullary canals*), as in the vaso-dentine constituting the central part of the dentine in Sloths and Megatherium. The Medullary canals of Tubulidentata (Orycteropus), which lie parallel to each other and to the long axis of the tooth, are regarded as the pulp cavities of a series of denticles fused together to form a compound tooth.

The Dentinal Tubuli commonly pursue a wavy and nearly parallel, though necessarily radiating course from the pulp cavity towards the superficial surface to which they are perpendicular. The primary branches are given off dichotomously.

The distinction between Medullary canals and Dentinal Tubuli may perhaps seem somewhat arbitrary, these structures constituting a continuous and apparently single system of tubes. If, however, we restrict the expression Medullary canals to the larger tubes, which in recent teeth demonstrably do, and in dry and fossil ones probably did, contain vascular extensions of the pulp, and limit the designation Dentinal Tubuli to those off-shoots from the former which are obviously too small to permit the passage of blood, we shall derive much advantage, for descriptive purposes, from the use of such terms.

The Enamel is plainly divisible into a series of closely co-adapted prismatic fibres. Certain species, Sloths among others, having no enamel, are included by some authors in a group called Inenamellata.

In the course of their development the teeth pass through all the grades already described, viz., the papillary, the follicular, the capsular, and the eruptive stages, previously to the last named of which they become included in alveolar cavities of the jaw bones. There are never more than two sets of teeth, unless the case of the Elephant's molars be considered an exception. The first set are named Decidous or Milk, the second Permanent teeth. In some Mammals only one set is formed, and these members of the class are named Monophyodont, while those which are provided with both sets

are included in the term Diphyodont. Where two sets are produced the second set is derived from the first by a process of budding.

The number of teeth being, with few exceptions, constant in each species, and the form, position, and use being analogous in the whole class, it has been found possible to express these relations in an abbreviated form termed the Dental Formula.

Thus if the letters I., C., PM., and M, be understood to indicate Incisors, Canines, Molars having vertical predecessors, and Molars having no such predecessors, respectively; figures placed above a horizontal line to signify the number of teeth of one category in one half of the upper jaw, and those placed below the same line to refer to the corresponding teeth of one-half of the lower jaw, the dental formula of man may be written as follows :—

$$\text{I. } \frac{2}{2},\ \text{C. } \frac{1}{1},\ \text{PM. } \frac{2}{2},\ \text{M. } \frac{3}{3}.$$

The dentition on the two halves of each jaw being, with rare exceptions (Narwhal) symmetrical, if the figures in this formula be doubled, the total number of teeth of each kind will be obtained.

The Deciduous, which differs from the Permanent dentition in the lesser number of molars, may be expressed in a similar manner by placing the letter D before each of the other letters. The number of permanent teeth is very different in different species, being reduced to one, of functional size, in the Narwhal (Monodon Monoceros), and reaching to as many as 220 in the Dolphin named Pontoporia; but the number is never so excessive as in some fishes.

REPTILIA.

No single character can be considered as absolutely distinctive of this class. The teeth may in position be confined to the Maxillæ, Pre-maxillæ, and Mandible, as in Crocodiles, or they may in addition be attached to the Pterygoid, as in some Sauria (Lizards), or to both the Pterygoid and Palatine bones, as in Ophidia (Serpents).

The base of the tooth is never divided into two or more separate fangs. In the majority of cases the tissue of the teeth becomes continuous with that of the bones which support the latter, and then these are anchylosed, in Pleurodont Lacertilia to the inner side of a bony parapet, in Acrodont Lacertilia to the edge of the jaw bone, in many other Sauria, and in the greater number of Ophidia to the bottom of a shallow socket. The teeth remain, however, ununited to the bone in

Crocodilia, Plesiosauria, and Ichthyosauria. In the two former groups they are implanted in distinct bony sockets, and in the latter they lie in a common osseous groove. The shape of the tooth is in almost every case conical, or some uncomplicated modification of that form. The most remarkable exception to this rule is met with in the poison fang of Ophidia. The apparently simply conical form of this organ is produced by the wrapping of a compressed lamellar tooth, in the progress of development, round the poison duct, until its edges meet and thus form a complete cylindrical sheath for the duct. The latter, therefore, though it may at first sight seem to occupy the usual position of the pulp cavity, is in reality outside of the tooth. The division of the tooth into Crown, Fang, and Cervix is seldom distinct. The prevailing similarity of form, size, and use in the same individual precludes, in general, the possibility of classifying the teeth under the several categories of Incisors, Canines, and Molars. This circumstance, taken together with their frequent variability in number in animals of the same species, renders the use of a Dental Formula impracticable. The pulp cavity is normally of simple form. It is, however, compressed and bent into a semi-cylindrical curve in the poison fangs of serpents, and in Iguanodon it sends off Medullary canals into the Dentine.

The Dentinal Tubuli exhibit as simple an arrangement as those of Mammals, namely, that of a close set series of radiating, yet almost parallel, branching tubes, which lie at right angles to the peripheral surface of the tooth. The comparatively thin layer of Enamel, sometimes entirely absent, often forms only a partial investment for the the crown of the tooth. It is in numerous cases apparently structureless, and even where structure is demonstrable, this consists of extremely fine, not always clearly defined, fibres, which do not present the distinctly prismatic form so characteristically developed in Mammalia. The pulp cavity often becomes obliterated through the conversion of the pulp into true bone. In those reptiles in which the process of development has been observed, the papillary has been found to be succeeded by the follicular and capsular stages; but the teeth never become included in completely closed osseous alveoli. The dentition of reptiles is not limited to one or two sets of teeth, the latter being shed and replaced by new ones in indefinite succession throughout the life of the individual.

The number of teeth is never so small as in some Mammals, nor, on the other hand, is it ever so great as in many fishes.

AMPHIBIA (FROGS, NEWTS, &C.)

The characters of the teeth in these animals are for the most part similar to those of reptiles. The presence, however, of a series of teeth, arranged in one or occasionally several curves more or less parallel to that of the teeth situated on the margin of the upper jaw, and seated upon the bones called Vomers, is considered to be highly characteristic of the group. The pulp cavity exhibits, moreover, in Labyrinthodon a peculiar complexity of structure which is only paralleled, and then in a less marked degree, by that of the teeth of Ichthyosaurus, many Ganoid, and a few other fishes. This consists in the occurrence of a series of longitudinal lamellar processes, with lateral off-shoots, which radiate from a contracted central cavity, and reach nearly to the periphery of the tooth. The dentine which bounds these extensions of the pulp cavity presents a corresponding series of folds embracing the latter, and penetrating deeply towards the centre of the tooth. Yet the minute structure of the dentine composing these tortuous convolutions displays that comparative simplicity which is normal in Mammals and Reptiles, the Dentinal Tubuli being here also parallel to one another, and perpendicular, not indeed to the general superficies of the tooth, but to the surface of each fold of Dentine.

PISCES (FISHES).

The endless variety in position, attachment, form, size, structure, development, and number, renders it almost a hopeless task to seek for any single well-defined character which shall be common to even a small majority of the species belonging to this division of the animal kingdom. Nor can many characters be adduced which are peculiar to the class. Nevertheless, there are not a few cases in which a review of the combination of characters present in a tooth will enable us to form a rational conclusion as to whether or not it formed part of an animal constructed on the Piscine type.

The teeth may be supported by several, or, in some fishes, by nearly all of the following bones :—The Maxillary, Premaxillary, Mandibular, Vomerine, Palatine, Pterygoid, Parasphenoid, Hypopharyngeal, Epipharyngeal, Basioccipital, Branchial, and Hyoid. In no other

class are teeth situated in the median plane of the body, as is the case with the broad dental plates of Myliobatis. As a rule they are united by continuity of tissue with the subjacent bone, this being the case, though only to a slight extent, even in Sphyræna and some other genera in which they are lodged in sockets. The teeth of Plagiostomi, (Sharks, Dog-fishes, Rays), are, however, marked exceptions, for their attachment to the cartilaginous or partially calcified jaws is effected by ligament only. In shape and size the variety is exceedingly great. They may be elongated into a cone, a cylinder, or a prism, terminated by an acute, blunt, bifid, or multifid free extremity. They may have a compressed laminar form, the free border of which may constitute two sides of a triangle, or may present a curved or a horizontal edge, and may further be dentated, crenated, or serrated. Lastly, they may be more or less depressed, and attached by a broad base, the free surface being convex or flat, with a smooth, wrinkled, ridged, or mammilated superficies, the circumference exhibiting a circular, elliptical, quadrangular, triangular, or beautifully regular six-sided outline. Nor is the foregoing description anything like an exhaustive one, for all sorts of intermediate forms exist. The teeth are sometimes so minute that when closely approximated, as they usually are in such cases, they resemble the pile of velvet, and on the other hand they may, as in the genus Carcharadon of tertiary geological age, measure six inches in one direction and five in another.

It would, no doubt, be possible to classify the teeth of fishes according to their use, their form, or their position; but such a classification would be without advantage to the comparative anatomist, seeing that use, form, and position do not bear that constant and definite relation to one another which prevails in Mammalia.

The terms Incisor, Canine, and Molar, occasionally used by the Ichthyologist, are only applicable to particular species or groups of fishes.

The pulp cavity, as in Lophius, and Pharyngeal teeth of Labrus, may present a simple, usually conical, form; but it is far more frequently continuous with tubular prolongations, Medullary canals, which extend to a greater or less depth into the dentine. It is somtimes, as in Pristis and Myliobatis, divided into a series of parallel Medullary canals, from which the

Dentinal Tubuli pass off at right angles, the adjoining canals seldom anastomosing, so that each Medullary canal, with its system of tubuli, may be regarded as a complete denticle, an arrangement which is essentially similar to the exceptional case of Orycteropus in Mammalia, but which in this class is exemplified by several species. The Medullary canals in other cases divide and sub divide into numerous branches, which anastomose frequently, and thus produce a network from which the Dentinal Tubuli radiate in all directions into the substance of the dentine. This is a very common, and also, I am inclined to believe, the most characteristic structural modification of dental tissue in fishes. In the teeth of the extinct genera Ptychodus, Psammodus, Acrodus, and some others, a condition intermediate between the two last described exists. Here the Medullary canals, while holding a nearly parallel course, give off at very acute angles a small number of branches, each of which represents the axis of a tolerably distinct system of Dentinal Tubuli.

The pulp cavity of the teeth of many Ganoid and a few other fishes shows a more or less advanced stage of that labyrinthine structure which attains its most complete development in the gigantic Amphibians of the Trias.

The Dentinal Tubuli, though in some teeth arranged parallel to one another, and at right angles to the surface of the tooth, in others decussate at various angles, and may exhibit a still more complicated appearance by breaking up into innumerable excessively fine branches, which unite to form a close network. A layer of tissue, having a similar relation to the dentine, as regards position and density, to that which the enamel holds to the latter substance in mammalia, is frequently observed; but this tissue does not, on microscopal examination, display those structural characters which so clearly define the enamel in the class named. It most commonly, indeed, appears to be devoid of structure. Sometimes it resembles very closely the subjacent dentine, and is in these cases penetrated like it by branching tubuli.

The outer ends of these Tubuli are, however, occasionally, as in the Incisors of Sargus and the pharyngeal teeth of Scarus, unlike those of the Dentine, wider than their inner terminations, and then their branches are directed towards the centre of the tooth. Many

teeth are entirely devoid of an outer covering corresponding to enamel. In Sphyræna and Sparidæ (Breams), the teeth become imbedded in closed alveolar cavities, as in Mammals, from which they emerge by a true eruptive process. It is a noteworthy circumstance that the Incisor teeth of Sargus Ovis (Sheep's Head Fish), which are examples of this mode of development, also resemble in no small degree, as regards size and shape, the Incisors of Man.

With very few exceptions, the teeth are shed and replaced uninterruptedly throughout the fish's existence. The number of teeth in a great many fishes exceeds computation; in some, on the other hand, it is reduced to four, *e.g.*, Ceratodus.

In the foregoing intentionally compressed summary of characters I have endeavoured to confine myself to those points which can be made use of in the determination of fossils, and I have consequently referred to few, and only striking, exceptions. For like reasons, I have not given the characters of cement, as these are in all classes the same as those of the bones of the animals to whom the teeth belong; and this substance may, moreover, be absent, or exhibit all degrees of development, in each and every class. I have also purposely omitted any allusion to those minute spaces (calcigerous cells of Owen) in the dentine, which so closely resemble the Lacunæ of Bone, and in which many branches of the Dentinal Tubuli terminate. The teeth of Monotremata and Cyclostomata have been excluded, as they are not now regarded in the light of true teeth, but are considered to represent modifications of the Ecderonic layer of the mucous membrane. I shall now, in illustration of the practical bearing of the preceding generalizations, bring under your notice examples of fossil teeth from each of the four classes—Mammalia, Reptilia, Amphibia, and Pisces.

It is worthy of note, in passing, that Birds, though edentulous in the sense of being deprived of functional teeth, are not entirely devoid of the rudiments of those organs. The embryoes of Psittacidæ, for instance, possess dental papillæ, with caps of dentine. If it be possible for such rudimentary structures to exist as isolated fossils, their discovery would, I am afraid, prove a source of sad perplexity to comparative Anatomists.

MICROLESTES.

I have chosen the teeth of this genus as an example of those of the class Mammalia for the following reasons :—

1st. They are among the most ancient remains of Mammalian life that have yet been brought to light.

2nd. The determinations of Palæontologists have in this case been necessarily based solely on teeth.

3rd. The geological formation in which they have been found is represented in our own neighbourhood (*e.g.*, at Larne, and Collon Glen), by the Avicula contorta shales ; and we may, therefore, possibly meet with these structures associated, let us hope, with portions of the skeleton.

These teeth were discovered in the year 1847, at Diegerloch, about two miles from Stuttgardt, in the bone bed of the Würtemberg Keuper, and the generic name was given to the animal by Pleiniger. In the year 1858 Mr. Charles Moore encountered similar teeth in beds of Rhætic age, near Frome, in Somersetshire.

The roots of the teeth from Stuttgardt are divided into two distinct, dissimilar, slightly diverging fangs. The crowns are somewhat laterally compressed, and surmounted by six angular, conical cusps. The first of these characters lead to the conclusion that the animal belonged to the class Mammalia. The form of the crown seems to indicate the insectivorous nature of its food.

Professor Owen recognises certain characters which appear to him to show an affinity to the Banded Anteater (Myrmecobius fasciatus) of New South Wales ; and he consequently classes Microlestes with the Insectivorous Marsupials.

The presence of two fangs of the form described is certainly very convincing evidence of the Mammalian nature of the animal. The structure of the crown also renders it probable that its food consisted of insects, though even on this surmise we must not build too much, for the form of the working surface of the tooth does not always point out the nature of the food. Professor Huxley's remarks with reference to Bears should teach us caution in a case like the present one. He writes :—

"It is a remarkable circumstance that the teeth of frugivorous and carnivorous bears exhibit no such differences as would lead to a suspicion of their complete

difference of habit, if we were acquainted with these animals only in the condition of fossils."

The marsupial affinities of Microlestes appear to me to be entirely a matter of conjecture, founded upon the resemblance of the teeth to those of other fossil Mammals of early geological date, which, being found in union with jawbones, have afforded a wider basis for deduction, and a belief, in accordance with the theory of progressive development, that the earlier forms of Mammalian life must belong to what is considered a lower type.

IGUANODON.

The teeth of Iguanodon are interesting reptilian fossils for several reasons, but especially on account of their furnishing a remarkable example of the verification by subsequently revealed facts of conclusions drawn by comparative anatomists from the evidence afforded by isolated teeth. They were first discovered by Mantell in the Wealden formation of Tilgate Forest. He sent them to several English and Continental naturalists, with a request that they would express an opinion as to the affinities of the animal which at one time possessed them. Cuvier's reply was the only one in which an attempt was made to solve the question proposed. The following is an extract from his letter :—" Ces dents me sont certainement inconnues ; elles ne sont point d'un animal carnassier, et cependant je crois qu'elles appartiennent, vu leur peu de complication, leur dentulure sur les bords, et la couche mince d'émail qui les revêt, a l'ordre des reptiles. A l'apparence extérieure on pourrait aussi les prendre pour des dents de poissons analogues aux tétrodons on aux diodons ; mais leur structure intérieure est fort différente de celles-la. N'aurions nous pas ici un animal nonveau, un reptile herbivore ? &c."

Stimulated by these remarks to make further researches, Dr. Mantell examined the teeth of recent reptiles preserved in the Royal College of Surgeons, when he observed that the teeth of an Iguana resembled very closely the fossil ones. Dr. Mantell also inferred from the appearance of the base that it was adherent by its outer side to the inner side of a bony parapet of the jaw. The teeth were next submitted to the inspection of Professor Owen, who has described their configuration and microscopical structure in his "Odontography." The following is a brief description of the teeth :—

The elongated, sub-cylindrical, and contracted base expands into a laterally compressed pointed crown, which presents an internal smooth convex surface, an outer surface furnished with three vertical ridges, and an anterior and posterior serrated border. Each of the serrations is a short, tranverse, notched ridge. A pulp cavity is present in young teeth, and from this extensions in the form of tubular Medullary canals, about $\frac{1}{1250}$th of an inch in diameter, proceed towards the inner surface, but are absent from the outer half of the tooth. The canals are separated by an interval amounting to 6 or 8 times their own diameter. Some of them have been seen to divide once in their course from the pulp cavity.

The Dentinal Tubuli, averaging the $\frac{1}{25000}$th of an inch in diameter, extend from the pulp cavity in a direction parallel to that of the Medullary canals, and perpendicular to the surface of the tooth. They are distant from one another about the $\frac{1}{6000}$th of an inch, exhibit a small number of large primary and very numerous secondary curvatures, and give off many branches. The enamel invests with a thin layer the outer side of the tooth, but is not found elsewhere. It is minutely but indistinctly fibrous in structure.

The apex of many of the teeth has evidently been worn away by use, and the summit of the crown in these presents a flattened area which slopes downwards and inwards so as to encroach more upon the inner than the outer surface. In such cases the pulp cavity is obliterated, and its place occupied by bone. This substance, having probably yielded less to wear than the dentine, projects from the centre of the abraded surface. The discovery of jaw bones with teeth attached, together with various other osseous remains of the animal, has confirmed the opinion expressed by Cuvier, Iguanodon being now included in a group of reptiles termed Deinosauria. When we come, however, to examine critically the characters upon which Cuvier apparently relied, viz., simplicity of form, thinness of the coat of enamel, and marginal serrations, we must admit that they by no means warranted the conclusion at which he arrived, for simplicity of form is met with in particular groups of all classes ; for example in Edentata and Cetace among Mammalia, in the greater number of Amphibia, and in numerous fishes. A thin and partial coat of enamel occurs in the mammalian Physeter. Marginal serrations are common in fishes (*e.g.*,

Sharks). Nor are the results of the microscopical examination of Owen more conclusive, for dentine, permeated by vascular Medullary canals, disposed in a manner very similar to that of the fossil tooth, is seen in Sloths and Megatherium of the class Mammalia, and in some fishes, while Professor Owen states that this modification of dental structure is quite peculiar, in the class Reptilia, to Iguanodon itself. Ossification of the pulp is also of frequent occurrence in all dentigerous classes.

The indications of the mode of attachment observed by Mantell, suggesting a relationship to Pleurodont Lacertilia, are, in my mind, of more importance than all the other characters of the teeth put together. I am, nevertheless, aware that the attachment is now believed not to have been effected by bony union.

LABYRINTHODON.

Among Amphibia the teeth of Labyrinthodon are, for a like reason to that given in the case of Ignanodon, of special interest. These teeth were, in the first instance, found in the Keuper Sandstone (Alaunschiefer) of Würtemberg, and the related animal was named Mastodonsaurus by Professor Jaeger, in the belief that it was a Saurian Reptile.

Teeth very like them were afterwards procured in sandstone of the Triassic period in Warwickshire, and were figured and described by Messrs. Murchison and Strickland. With a view to the settlement of a disputed question concerning the relative ages of the Würtemberg strata and the Warwickshire sandstone, Professor Owen was requested to compare the teeth from the respective rocks. Professor Owen, being aware that there had been found in the same beds with the Würtemberg teeth an occipital bone, provided with two large and distinct articular condyles, surmised that the teeth and occipital bone were probably to be referred to the same genus or species ; and, recognising in the two condyles a character peculiar to Amphibia among vertebrates not Mammalian, concluded that the Würtemberg fossils belonged to an Amphibian. He, in the first place, submitted the teeth of Jaeger's Mastodonsaurus to microscopical examination, and then discovered the remarkable labyrinthine structure which has already been described in giving the general characters of Amphibian teeth. Professor Owen next examined microscopically the teeth from the Warwickshire sandstone, and found that they exhibited a structure

almost identical with that of the Würtemberg specimens. He consequently substituted for Mastodonsaurus the more appropriate generic designation of Labyrinthodon, and referred the Warwickshire teeth to that genus. Specimens of the upper jaw and adjoining bones having been subsequently transmitted to him, he ascertained that a row of vomerine teeth lie within and parallel to the Maxillary series. The discovery and examination of other parts of the skeleton have still further elucidated the affinities of Labyrinthodon, and its claim to a place in the class Amphibia may now be considered as tolerably conclusively established.

The teeth are of a slightly curved conical shape, and marked by longitudinal striæ, which are much more distinct in some specimens than in others. The striæ extend from the base for a variable distance, in different teeth, towards the apex, which they never in any case reach. The pulp capity is narrow, and contracts to a mere line near the apex. A layer of cement is said to cover the entire surface, and to follow every inflection of the dentine. The teeth are anchylosed to the bottom of shallow pits. Some of them are of large size, one from Würtemberg measuring three and a-half inches from base to apex, and one inch and a-half across the base. It will be observed that in the foregoing instance the external form of the tooth yields very insufficient evidence concerning the nature of the animal. Longitudinal striation is, however, certainly not a Mammalian character, and its presence here warranted in some measure the exclusion of that class. The peculiar radiating folds of dentine have not, so far as I can ascertain, been found in any but animals of an ichthyic type, and this circumstance might have furnished grounds for the conjecture that, if the tooth really showed Reptilian affinities, it belonged to an animal intermediate in its organisation between Reptiles and Fishes.

It appears to me, however, that the circumstance which had most to do with the early allocation of Labyrinthodon to its proper class was the recognition of the Amphibian structure of the associated occipital bone.

CARCHARODON.

Owing to the perishable nature of the skeleton and the slight attachment thereto of the teeth, the latter appendages occur, in the present genus, almost invariably, as completely isolated remains.

For this reason, and also because Mr. Young exhibited fine specimens of them, and described the physico-geological relations of the strata in which they are found, at our last meeting, I have been induced to make use of them in illustration of fishes' teeth, though they are far from typical examples of the modifications of dental structure peculiar to the class.

These teeth are entombed in Tertiary (Cainozoic) rocks. The specimens exhibited by Mr. Young belong, I believe, to the Carcharodon Megalodon, an Eocene species. Some of the teeth of this species are of extraordinary dimensions. In one tooth the length from base to apex was six inches, and the breadth across the base five inches. The form is that of a triangular plate with an acuminate apex and finely dentated edges. Of the two surfaces the anterior one is nearly flat, and the posterior transversely convex. The base is bilobed. The entire tooth is slightly curved in a vertical direction, the convexity of the curve being directed forward.

The substance of the attached portion of the base, and of the interior of the remainder of the tooth is traversed by branching Medullary canals. Those branches which are near the centre of the tooth lie nearly parallel with its long axis, while the lateral ones are directed towards its periphery, and successively assume a more transverse course the nearer they are situated to the base, the lowest descending into the lobes of the latter.

These canals give off lateral branches, at right angles, which communicate by frequent anastomoses, and form a network. From the sides of, and perpendicular to, the primary Medullary canals and their larger branches, the Dentinal Tubuli pass into the intermediate spaces, and divide into numerous twigs, which unite to constitute an intricate series of fine reticulations. The Dentinal Tubuli which are situated near the superficial surface of the tooth are directed outwards at right angles to that surface. A layer of dense enamel-like, but apparently structureless, substance invests the whole of the unattached surface, and gives to it a highly polished aspect. Teeth of the above described external form have not, that I am aware of, been seen in any other class than Pisces. The arrangement of the Medullary canals is very characteristic of that class. So also is the close and intricate network formed by the Dentinal Tubuli. An examination of the

base of the tooth reveals no signs of its original implantation in a socket or anchylosis to a bone, a negative character indicating its relationship to the teeth of the shark tribe. Its resemblance to the teeth of the recent genus Carcharias is so great that no comparative anatomist has, to my knowledge, hesitated to refer it to an allied genus.

I am not in this case disposed to object to the determination, though I fail to see the absolute necessity of the connection.

If, in the preceding remarks, I have ventured to criticise the validity of the principles by which the able and thoroughly qualified investigators alluded to have in some instances been apparently guided, yet I am prepared to admit that I may not have fairly estimated the amount of knowledge which has been brought to bear upon the solution of the questions at issue. For I am well aware that extensive practical acquaintance with animal structures imparts a sort quasi-intuitive perception of relations which cannot always be readily expressed in words.

[Many other examples of fossil teeth, besides those described in the preceding abstract, were referred to. The paper was also illustrated by an extensive collection of recent and fossil teeth and jaws, and by microscopical preparations.]

9th April, 1873.

Joseph John Murphy, Esq., the President of the Society, in the Chair.

A Paper was read by JOHN PURSER, Esq., M.A., M.R.I.A.,

On the Rainbow, Halos, and Coronæ.

The lecturer commenced by a brief review of the leading principles of the science of light, the velocity of its propagation as determined by Roemer, Newton's analysis of the solar beam, the evidence on which scientific men have adopted the conclusion that light consists in the vibrations of a highly elastic medium, the analogy between the modes of propagation of light and sound, how far the analogy extends and where it terminates, the general phenomena of the interference of vibrations as illustrated by co-existing systems of waves traversing a sheet of water and by the vibrations of an elastic string.

He then passed on to the consideration of the application of these principles to the explanation of the phenomena which formed the subject of the lecture.

THE RAINBOW.

The Rainbow is a magnificent spectrum of the sun's light in which the part of the prism is played by the drops of falling rain; not that we can see all the colours formed by the separation of the rays as they emerge from any single drop, but that our eye is always in such a position as to catch the red rays coming from one set of drops, the green from others, and similarly for the rest.

To explain more accurately how this spectrum is produced, the lecturer took, to represent a drop of rain, a hollow glass globe filled with water. When the observer places the globe on the side opposite

to a candle he sees in the globe a bright speck of light, produced by the reflection of the candle. This reflection is formed by rays which, entering the globe, are reflected from its inner surface. As the globe is moved to one side the small reflection of the candle is still seen, till, on the globe reaching a certain position, this reflection waxes greatly brighter; and, if the globe be moved slightly beyond this point, the reflection disappears altogether.

Such, at least, would be the appearance presented, were we experimenting with a candle which emitted light of only one colour. It follows that, if the room were filled with drops of rain, all the drops within a certain circle, or rather cone, would exhibit the little bright speck of light which constitutes the reflection of the candle, that the drops situated round the edge of this cone would show far more brilliant reflections than any of the rest, and that outside this cone the drops would show no reflections of this class. Were the drops so small as to be separately indistinguishable, the consequence would clearly be that we should see a circle of light, fringed with a particularly bright rim and comparative darkness outside.

Inasmuch as the light from the candle which is thus thrown back is twice bent, once on entering, and again on emerging from the drop, it will be easily understood that the question, whether a drop can or cannot reflect light to the eye of the observer depends upon the amount of this refraction, and, therefore, upon the colour of the light. In other words, that to each different coloured light which the candle emits will correspond a circle of that colour, girt about with a similarly coloured bright rim. Corresponding to the red rays we shall have a red circle, with a red band running round its circumference; to the violet rays a somewhat smaller circle, concentric with the first, and fringed with a bright violet band; and, for the intermediate colours, circles of intermediate size, each with its appropriate band. The successive bright bands bounding the circles form the Rainbow, the bright space inside the bow being luminous, but the luminosity being that of white light, and for this reason :—Inside the bow we have superposed the whole system of coloured circles corresponding to the colours which originally constituted white light, and which accordingly, now brought together again, will restore the same.

The difference in the brightness of the light inside and outside the Rainbow is very marked, and is one of the features which greatly adds to its beauty.

The Secondary Bow is formed in a similar way, the only difference being that it is produced by a reflection of the sun, formed by rays which have been twice reflected before emergence on the interior surfaces of drops, and in this bow the colours are reversed. It is much less brilliant than the Primary Bow, because the light is weakened by every reflection.

The bows of the third and fourth orders, due to three and to four reflections in the drops of rain, are, of course, feebler still, not, however, so much so as to prevent our seeing them, were it not that they are projected on the clouds on the side towards the sun, and that the glare of the sun's beams masks them.

SUPERNUMERARY BOWS.

We may frequently observe in looking at a rainbow of more than ordinary brilliancy that the brighter colours repeat themselves on the inside of the bow, so that the appearance presented is that of several bows in close juxtaposition. These additional colours go by the name of the Supernumerary Bows, and were satisfactorily explained by Dr. Thomas Young, on the principle of the interference of light.

To understand how they are produced it is necessary to revise the explanation already given by means of the glass globe and the candle's reflection. It is not a strictly accurate account of what takes place to say (at least supposing this globe as small as a rain-drop) that as the globe is gradually moved to one side the little reflection of the candle undergoes no alteration in brightness till its final sudden accession of brilliancy before extinction. On the contrary, as the globe drew near to this critical position the little speck of light would pass through several alterations, now of brightness, now of nearly complete extinction. These are due to the circumstance that the light which forms the little image is made up of two pencils of rays which, not having travelled precisely equivalent paths in the rain-drop, interfere and, in some positions, cancel, in others reinforce each other.

Thus, instead of the account of the matter previously given when we did not take interference into our calculations, that is, instead of a

circle of light for each colour, fringed by a single bright band, we should have each circle fringed by several such bands, with intervals of darkness. When we remember that on these are superimposed the circles corresponding to the other colours, each with its own system of bands, we see that the appearance presented will be precisely that we are endeavouring to account for.

The reason we only occasionally see the Supernumerary Bows is that their position depends upon the size of the rain-drops. The smaller the drops the wider is the interval between the different colours in the Bow, and their repetition in the Supernumerary Bows. It follows that if the rain-drops differ much in size, as they generally do, each set of drops will, as it were, paint upon the clouds differently placed Supernumerary Bows, the colours of which will be blended together, and leave no separate trace.

HALOS.

These are frequently seen round the sun and moon in northern latitudes, and occasionally in our own. They consist of many various circles and fractions of circles. Some of the more prominent of these seen, sometimes separately and sometimes altogether, are the following:—

1. A coloured circle, red on the inside, violet on the outside, concentric with the sun, with an angular radius of from 22° to 23°.

2. A similar circle with angular radius of 46°.

3. A circular band of light, uncoloured, running parallel to the horizon and passing through the sun's disk.

4. A vertical column of light, also uncoloured, passing through the sun's disk, and best seen when the sun is close to the horizon, or a few degrees below it.

The circles (1) and (2), concentric with the sun, are explained on the same principles as the Rainbow, except that the rays of light, instead of being reflected by drops of rain, are reflected from the inner surfaces of minute hexagonal crystals of ice. Their mode of formation may be illustrated by allowing a solution of alum to crystallize on the surface of a watch-glass. If we then look at a candle through the glass thus covered with crystals we see beautiful specimens of Halos.

[The Halos so produced were exhibited.]

In the production of the vertical and horizontal beams (3) and (4) the force of gravity must have a share, for in no other way could we account for these directions being followed in preference to any other.

The way in which gravity influences the direction taken is the following :—When these halos are seen, the air is full of very minute prisms of ice of many varieties of form. Many of these forms in falling through the air will have a prevailing tendency to pose themselves so that certain faces of the crystals will be vertical, and the sun's rays reflected from such faces will give the appearance (3) of a belt of light running parallel to the horizon, at the altitude of the sun. This belt has been called the Parhelic Circle. The vertical column (4) is due to the reflection of the sun in the faces of other crystals, probably in the form of thin laminæ, which, as they descend through the air, keep balancing themselves to and fro about a horizontal position.

Such a column of light has been most aptly compared to that which we see when the moon is reflected by the surface of water ruffled by the wind, where the effect is manifestly due to the light thrown off from the moving faces of the waves.

CORONÆ.

The rings of colour to which the name of Coronæ or Crowns has been appropriated are familiar to us all. They are those which we constantly see whenever a light cirrus cloud passes across the moon. They may be as frequently seen round the sun if we take the precaution to observe it through a dark glass, otherwise the glare of the sky in the neighbourhoood of the sun masks them.

These rings are differenced from the Halos of which we have been speaking by several very distinctive marks. In the first place the smallest of the two Halos has a radius of 22°, and within this circle there is no colour, whereas the colours of the Coronae begin from the very edge of the moon's disk.

Again, the Halos have the red on the inner rim, while in the Coronæ the order of the colours is reversed, and the blue or violet always innermost.

The dimensions of the Coronæ are very variable, the colour sometimes extending only a few degrees from the moon, at others taking a much wider sweep.

The Coronæ, thus differing essentially in their characteristics from the Halos, owe their origin to a totally distinct cause.

That they are produced by the action of the clouds through which the rays of the moon are shining is obvious; but the operation of the cloud particles upon the light is quite different from their operation in the production of the Rainbow and the Halos.

Whenever between an observer and a source of light a number of very small opaque or semi-opaque particles are scattered regularly or irregularly, provided only that they are on the whole of the same size, there will always be seen in concentric circles round the light coloured rings or crowns more or less vivid. The diameter of these rings will depend only on the size of the particles; the smaller the particles are the larger the rings.

Such rays, for example, are seen, in certain states of the eye, round the flame of a candle, the motes which in this case produce them having their seat in the humours of the eye itself.

We get beautiful specimens of them when we look at a candle through two pieces of glass between which has been placed a little oil mixed with Lycopodium powder, or with that of the common Puff-ball.

The seeds of which the Lycopodium powder is composed are about $\frac{1}{940}$ of an inch in diameter, while the spores of the Puff-ball are $\frac{1}{8500}$ of an inch in a diameter, or 9-times smaller than the former.

Accordingly, we shall find that the rings produced by the Puff-ball are far larger and more beautiful.

[Both were exhibited by the lecturer.]

It will, therefore, be readily allowed that the small spherical particles of water which constitute a thin cloud will have a similar effect, and that the finer is the mist the larger will be the Coronæ. The complete account of the *modus operandi* by which the interposition of these fine particles produce this singular effect is one of the most important achievements of the undulatory theory of light. A very general explanation must suffice at present.

The waves of light are plane waves: the meaning of this statement is, that all the portions of the ether in one and the same plane are vibrating in the same way. Now, as long as such a plane wave is unimpeded it moves forward perpendicularly to the plane front of the wave—in

other words, the course of the light is direct; but when such a plane wave, as it moves forward, is met by an obstacle which, as it were, cuts away a fragment of the wave, it may be easily understood that the portions of the wave near the edge are greatly modified by the loss of the neighbouring parts, and no longer travel forward with the rest of the wave but send out eddies of their own in oblique directions. These eddies, by their interference, produce special oblique beams of light and shade, and the directions of these beams will differ for the different colours of which the light is composed.

It can be established that, *cæteris paribus*, the deflection of the oblique beams will be greater for the longer waves than for the shorter. It is easily gathered from these laws that the appearance presented to the eye will be that of a system of coloured rings, surrounding the source of light, and that the order of their colours will be that always observed; the violet, which has the shortest wave-length, on the inside; and the red, which has the longest, on the outside.

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